OTHER BOOKS IN ARCHITECTURAL AND BUILDING SERIES.

Editor A. M. Chitty, M.A., F.R.I.B.A., A.M.T.P.I.

WOOD ADHESIVES

by

EDWARD H. PINTO

"In a civilisation such as ours there is no escape from the conclusion that any industry which does not rest on sound scientific principles must ultimately die. The day is gone beyond recall when we may do things simply hoping for the best. We must know exactly why we are doing them as far as the utmost resources of science can tell us so that we may control our manufacturing materials and not they us. Can we say that we have everything under strict control? We know too well that we cannot, and perhaps it is too much to ask this. But can we even say that we have our processes under such an amount of control as the available scientific knowledge permits ? Again we must confess the answer is 'No'. There needs much closer co-operation between scientist and technologist than exists to-day. They must work hand and glove together."

<div style="text-align: right">

W. T. Astbury, *Fundamentals of Fibre Structure*, p. 2 (Oxford, 1937).

</div>

First Published in 1948

FOREWORD

by E. H. B. Boulton, M.C., M.A.,
Technical Director of the Timber Development Association.

This is the first edition of a new book which deals with the subject of adhesives in a most systematic way, and it is, in fact, the only British book covering the whole field of modern adhesives. It thus provides a welcome and long-needed addition to the sparse literature on this particular aspect of timber technology.

Timber has been recognised more readily as an engineering material since the introduction of new adhesives and the building up of large sheets of wood, either in the form of plywoods or by various other methods of lamination. In fact, these adhesives are responsible for the new age in wood. In aircraft construction, such as training craft, gliders and the Mosquito, these new adhesives have proved their worth in many parts of the world and in continually changing climatic conditions. This is also true of many of the naval craft, which were designed with the aid of veneers and adhesives to withstand great pressure and continual changes of temperature from the Arctic circle to the equator. During the war the author was in a favoured position to study the latest technique and developments in the use of adhesives, and this book shows how much of the research work which has been done during the past seven years can now be utilised for the design and construction of many articles in wood for peace-time purposes.

Mr. Pinto is a great authority on the historical use of wood in all its phases and has contributed many articles on the subject. He is a great collector and possesses one of the most outstanding collections of "treen"—i.e. small wood objects—to be found in this country.

He writes as a practical wood-working constructor and with authority and a full understanding of timber as a raw material, and of timber which has been moulded by sculptors and craftsmen, as well as of modern methods of moulding timber with the aid of these new adhesives.

CONTENTS

FOREWORD AND ACKNOWLEDGMENTS

CONTENTS

9

CONTENTS

Melamine-formaldehydes—Their advantages and limitations—
Methods of application—Fortified urea cements—Thermoplastics—
Their particular uses and possibilities for the future.

CONTENTS

ILLUSTRATIONS

INTRODUCTION

UNTIL a few years ago "wood adhesives" to the majority of people meant glue. To the same majority, glue when cold meant a brown cake or jelly emitting an unpleasant odour, and glue when hot meant a sticky liquid giving off a yet stronger and more unpleasant smell. Now, all that is changed, and the lay and technical press talk familiarly about caseins, blood albumins, soya bean and cassava glues, resin-bonding, thermo-setting and thermo-plastic glues.

To many of the readers, and possibly some of the writers too, these terms are mysteries, and not only the general public but members of the woodworking trades as well are feeling the need for a clear picture of the varieties of adhesives which are now available to them in their work: the purposes for which each is best suited; their particular advantages, disadvantages and limitations; some knowledge of what they are; the plant and factory conditions which they require; how they should be prepared; and the precautions which should be taken if the best results are to be obtained.

This book attempts to do no more than give a simple and practical picture on these lines for the benefit of the practising or intending woodworker. A full attempt is not made within the compass of this work to give the history of adhesives from the angles of the chemist and physicist, although the latest glues and particularly the waterproof adhesives owe their development to the patient and brilliant research of these workers, who by their discoveries have opened up a new field of construction in timber.

Science has made possible and practical the use of glued-wood joints, either without or with the minimum of nails, screws or bolts, under conditions calling for extreme resistance to weather exposure. The needs of war production speeded up research and development and led to the successful use of glued joints in ship-building, aircraft construction, coach bodywork, engineering and building.

Plywood, blockboard and laminboard, three of the most useful glued-wood sheet materials, were until recently limited in their

uses to places where they did not come in contact with frequent or continuous moisture or extreme heat. Waterproof adhesives have altered all that, and their largest use, so far, has been in the extension of glued-wood sheet materials into "exterior" type plywood and other compressed wood materials, which are growing rapidly in favour and are manufactured in flat sheets suitable for wall sheathing, partitions, sub-floors, floor tiles, ceilings, roof linings, prefabricated hutting, shuttering and moulds for concrete, box beams and posts, gussets in roof trusses, external door panels, flush doors, special tanks and vats, draining boards, counter and table tops and shelving—subjected to frequent moisture. Simple curved sheets are being used extensively for tubes, barrels and silos, whilst the more intricate shapes are playing a large part in shipbuilding, aircraft and motor body work and in propeller and fan blades.

In the United States, where during the war timber was in better supply than here, it was utilised in conjunction with waterproof adhesives to save thousands of tons of steel each week.

Single-member glued laminated beams, ribs and arches were used largely, some for roof spans of over 60 feet. Tens of thousands of prefabricated buildings using waterproof plywood on glue-jointed framing were erected; miles of laminated wood pipes went into service; and laminated wood pulleys turned in engineering plants stretching from the Atlantic to the Pacific. Not all the above use or justify the use of fully waterproof adhesives. For many of the items enumerated, moisture-resistant glues and cements are easier to mix and apply and serve the purpose adequately.

Certain of the well-tried adhesives, such as the caseins and blood albumins in special mixes, possess high resistance to moisture and come under the heading of construction glues. The caseins are just as much plastics as are the newer synthetic resins. It is a great mistake to think that the waterproof adhesives have superseded or necessarily should supersede the older and well-tried glues. This is not the case; there appears to be a need for all the varieties of adhesives described in this book.

For convenience of classification, they are placed under six main headings:

(1) Animal glues.
(2) Casein and vegetable-protein glues.
(3) Vegetable (starch) glues.

(4) Blood-albumin glues.

(5) Liquid glues.

(6) Synthetic-resin adhesives.

No one of these adhesives is superior to the others in all respects; each variety has some specific quality which makes it the most suitable for a particular purpose.

The synthetic resins have opened up a completely new field for glued-wood construction, but it must be emphasised that there are many interior purposes for which they possess no advantages and for which the older glues are ideally suited, as well as being cheaper and much simpler in application.

It should also be borne in mind that the older glues have been tested, improved and proved satisfactory for certain purposes over many years, in some cases over centuries. The newer chemical products have not this advantage, though the stringent heat and moisture-resisting tests which they have withstood successfully give good grounds for believing that they will hold firmly over many years.

The use of glue in fabrication economises timber and helps design. It makes possible large flush surfaces and the utilisation of stable but uninteresting woods for core work and the conservation of rare and handsome but unstable woods for use in thin surface veneers. It also allows the creation of articles of intricate construction and unusual form, as well as the building up of offcuts and short ends into useful products.

It may not be known generally how ancient a craft is gluing. It was certainly not new at the time of the Exodus. Floyd L. Darrow in *The Story of An Ancient Craft* describes a sculptured mural of Thebes, dating from the time of Thothmes III—three thousand five hundred years ago—which shows a glue-pot on the fire, with the end of a stirring rod projecting. A workman, brush in hand, is shown applying glue to a wooden base. Another is depicted fitting a piece of veneer to a wooden core. An adze carelessly struck into the block of the same structure as the base indicates its more humble grade. A completely veneered and inlaid box figures conspicuously in the foreground.

In the great museums of the world are mummy-cases and furniture from the tombs of the Pharoahs which provide unmistakable evidence of glued joints and veneered surfaces. Murals show that the glue of Ancient Egypt was melted over a fire, spread with a brush and that the glued parts were held down

with stone slab cauls, weighted with bags, presumably filled with sand. It seems probable that the glue used at that time was basically similar to the animal and fish glues of the present day.

The Story of Furniture, translated from the German by A. Koeppen and C. Breuer, goes as far as to say:

> "*The ancient Egyptians already employed the art of ennobling an ordinary wood by gluing on thin layers of costly woods. For example, the corner-posts of a large mummy-case in the Berlin Museum are overlaid with a veneer almost one centimetre thick.*

> "*Glue was a favourite fastener. There were two kinds of glue, the common kind, joiner's glue made from animal offal and fish bladders and also the glue made from caustic lime and white of egg or casein, which had already been discovered by the Egyptians. Their wish to construct rich furniture at lower cost, as well as the experience that the use of a suitable core-wood makes flat pieces warp less than when heavy boards of costly woods were used, led them to adopt ply-work. This was cut with saws and fastened to an under layer of other wood with glue. They made table tops, chests, beds etc.*"

Whilst none has survived, we know that veneered furniture had a great vogue in Rome at the height of its glory. Hear what Pliny the Elder has to say in his *Natural History*, written nineteen hundred years ago:

> "*The citrus tree gave rise to a mania for fine tables, an extravagance with which the women reproach the men when they complain of their vast outlay upon pearls. Notwithstanding his moderate means, Cicero gave no less than one million sesterces for a veneered table of citrus wood.*"

Pliny goes on to say:

> "*The wood, too, of the beech is easily worked, although it is brittle and soft. Cut into thin layers of veneer, it is very flexible, but it is only used for the construction of boxes and desks. The wood, too, of the holm oak is cut into veneers of remarkable thinness, the colour of which is far from unsightly.*"

Pliny has also told us that the most highly prized possession of Cæsar was a beautifully veneered table. After the fall of Rome and the eclipse of civilisation through the triumph of the *Herrenvolk* of that time, the history of gluing, like that of most other arts and crafts, disappeared into darkness for a thousand years. How its revival came about is told briefly in the chapter on animal glues.

Chapter 1

TYPES OF WOOD ADHESIVES AND THEORIES OF ADHESION

Aꜱ WOOD adhesive may be in the form of a cement or a true
glue which sets by cooling or when the excess moisture
has been eliminated by

(a) absorption into the wood,

(b) pressure, or

(c) evaporation by heat.

The chemical composition of true glue does not change, its
"set" being mechanical. In consequence, animal glues, which are
typical of this group, can never be waterproof, being liable
always to re-absorb moisture. Cements differ inasmuch
as they undergo an irreversible chemical change in the process
of setting, and although not all cements are waterproof, the
waterproof adhesives are to be found in this group.

Unfortunately, manufacturers of wood adhesives use the terms
glue and cement as interchangeable for all types. Moreover,
there are adhesives which are neither true glues nor cements.
To add to the confusion, the word cement is apt to be regarded as
synonymous with Portland cement.

The next two points, why and how glues stick, are neither
easy to explain nor settled beyond dispute. It is, however,
generally accepted that both solid and liquid matter are built up
of innumerable molecules held together through a power of
mutual attraction known as cohesion. When this same force
acts on molecules that are in close contact, it is known as
adhesion.

Wood, as is well known, is absorbent, and this helps because
most glues are applied in liquid form, and, the cohesion of liquids
being less than that of solids, the molecular attraction increases
as the glue dries. The process is assisted further by contraction
of the glue in drying and by applying pressure simultaneously.
An excellent description of what occurs next is given by C. D.

Wood and T. G. Linn in *Plywoods* (W. & A. K. Johnston Ltd., 1942) ; they say:

"What happens now is that the glue is forced into the hollow spaces between the fibres of the wood. The glue does not penetrate the cell walls but merely enters the exposed openings of all cavities, at the same time retaining its own continuity. It should now gel—i.e. become semi-solid—and subsequently harden into a solid mass anchored firmly to the wood fibres.

"In addition to the force of molecular attraction, a certain keying effect is obtained. From the description given, it may be possible to visualise a layer of solidified glue from which appear on both surfaces countless tiny tentacles which have penetrated and twisted themselves around the wood fibres.

"Good glue is stronger than the material supplied by the growing tree to bind the wood fibres together, and consequently when the glue has effectively penetrated the texture of the wood, the entire structure is strengthened."

A word of caution is necessary here. Too thin a glue will lead to excessive penetration and starved glue joints; too high a temperature or too great a pressure will have the same effect.

B. Butterworth, B.Sc., of the Building Research Station, writing in a paper on "Adhesion and Adhesives", says:

"The Nature of the Common Adhesives and of Adhesion.— *An adhesive is a substance used to stick two surfaces together. Glue is the typical adhesive. It is a colloidal substance soluble in hot water and gives a viscous solution which sets to a gel on cooling. The formation of a strong glue joint depends upon this change from the sol to the gel condition. Many other substances besides glue are in common use as adhesives, the majority of them being colloids. The majority also are prepared solutions that do not require heating before application. The modern tendency in industry is increasingly towards the use of these so-called cold adhesives which are more convenient and economical in use than hot glues. With cold adhesives, setting depends upon absorption and evaporation only.*

"Colloids are in general much more suitable for practical use as adhesives than crystalloids because their solutions have properties of viscosity and surface tension which make them convenient to apply, and because they yield films having sufficient substance to fill the joint and sufficient strength and flexibility

18

to adapt themselves to stress without rupture. Nevertheless it has been shown by McBain and Lee that many substances not usually regarded as adhesives can give strong joints if melted between plane surfaces and allowed to solidify as thin films. Such substances might not satisfy all the requirements of an adhesive for practical use, particularly in respect of what McBain and Lee called 'deformability', but the results obtained with them threw light on the theory of adhesion, and confirmed the rules found in their studies of commercial adhesives. In considering the nature of adhesion it is necessary to distinguish the adhesion between two surfaces produced by a liquid filling the space between them, and that produced by a solid adhesive film. The strength of adhesion produced by a liquid is low, but it was shown by McBain and Lee that it is greater than could be accounted for by atmospheric pressure over the area of the joint. With the pure substances that they tested they found that the best lubricants were the worst adhesives. When the adhesive used is a solution, or is a liquid that is subsequently frozen in situ, e.g., solder, its behaviour in the liquid condition has an important effect on the finished joint. The liquid should wet both the surfaces to be joined, since otherwise the contact between the latter and the solid adhesive film will be imperfect. It is for this reason that wetting agents are often incorporated in adhesive solutions, especially in those for use on waxy or greasy surfaces.

"It is generally considered that the adhesion produced by a solid adhesive film may be of two kinds: specific adhesion, which is produced by molecular forces of the same order as those responsible for the cohesion of the different parts of a single substance, and mechanical adhesion, which consists in the keying of the adhesive around fibres and into crevices of the materials joined. Specific adhesion is the only possibility when the surfaces joined are plane, as in the case of the metal test pieces used by McBain and Hopkins, and may give joints of very high strength. Mechanical adhesion is a possibility with porous surfaces such as earthenware and wood, but it is difficult to decide whether, and if so, to what extent, it supplements or replaces specific adhesion, and in the important case of glued-wood joints opinions on this subject have been divided. McBain and his co-workers regarded glued-wood joints as mainly mechanical, whilst workers at the U.S. Forest Products Laboratory brought forward evidence to show that the adhesion is specific. More recently de Bruyne

has developed an explanation of adhesion in glued-wood joints which implies that the adhesion is specific. According to de Bruyne, provided pure or simple substances are used as adhesives, 'there is a good deal of evidence that strong joints can never be made to polar adherends with non-polar adhesives or to non-polar adherends with polar adhesives'. This de Bruyne describes as 'the basic rule of adhesion', and it certainly appears to explain many facts, though observations not compatible with it have been reported. For example, McBain and Lee showed that coumarin can give strong joints to both a polar adherend (wood) and a non-polar adherend (steel). Objections to the polarity theory have also been raised by Halls. It would seem that an entirely satisfactory theory of adhesion has still to be developed."

The article by Dr. N. A. de Bruyne referred to above was entitled "Why Does Glue Stick" and it appeared in the issue of *Wood* of March 1940. Dr. de Bruyne has kindly written a revised version of his article for this publication, which reads:

"*The ability of some materials to stick firmly to others is of fundamental importance in the paint industry, the plastics industry, the woodworking industry, the paper industry, in electroplating, and in engineering of all kinds. Why do some things stick together and others not? And why do the things that usually stick well sometimes fail to do so? Anyone who has used a paintbrush, a glue-pot or a soldering-iron must have asked such questions as these; it is only recently that it has been possible to give any satisfactory answer.*

Cohesive Forces: "*If we take two pieces of steel and weld them together we obtain a strong joint. In effect, the two pieces are made one and are held together by the cohesive forces of the steel. But if such cohesive forces are present, why is it not sufficient merely to lay the two pieces of iron together to obtain a strong joint? It is because these cohesive forces (unlike, for instance, the magnetic forces emanating from magnetised steel) are effective only over a very short distance, so that the natural roughness of the iron prevents contact except at a few points, and because the surface of iron, like every other surface, is contaminated with dirt (using the word in its widest sense). If we cleave a piece of mica very carefully and then immediately press the two cleavage surfaces together again, the adhesion (or more*

correctly the cohesion) is perfect, but if we leave the surfaces for any time the strength of the bond is much reduced. [See J. W. Obreimow, *P.P.S.* (A), *127*, 290 (1930); E. Orowan, *Z.f.Physik*, *82*, 256 (1933).]

"Again, it has been found that the exposure to air of freshly cut surfaces of paraffin, lead, tin, results in a reduction of the cohesion (Benedick and Sederholm, *Nature*, 22nd January, 1944; see also L. C. Bannister, *Nature*, p. 315, 11th March, 1944). *In order to join two pieces of iron it is necessary to use a liquid which will dissolve the dirt and which will make good contact everywhere with the rough surface, and then to cool the liquid until it solidifies. This is the process of soldering. Like welding, it depends for its effectiveness on short-range cohesive forces.*

"But now we come upon a new fact of great importance. Only certain liquids (or, if you prefer, 'molten solids') make effective solders. This is easily demonstrated by a simple experiment. Take two strips of gummed paper, moisten them and then press one strip on to a glass surface previously cleaned by rubbing with a linen rag under running water and the other strip on to a glass surface previously coated with a layer of paraffin wax by warming it and allowing a candle to drip on it. After a few minutes it will be found impossible to peel the paper off the clean glass surface while the paper on the wax surface is easily removed.

"Apparently, therefore, although some kinds of cohesive forces can interact with the cohesive forces of other materials to give strong joints, such as those between steel and solder, others cannot.

Two Kinds of Cohesive Forces: *"The clue to the inability of the gummed paper to stick to the wax surface lies in the old jingle 'similia similibus solvuntur' (like is dissolved by like) that has come down to us from the alchemists. Water, glycerine, alcohol mix together; benzene, paraffin, petrol will mix together. But water and petrol will not mix. Like mixes with like, and there are two main groups of 'like' substances: (1) the polar group, containing water and glycerine and so on; and (2) the non-polar group, containing such materials as benzene and petrol. Liquids within the polar group will mix with one another, and liquids within the non-polar group will mix with one another, but polar liquids will not mix with non-polar liquids.*

"*These rules, of course, are only of a rough-and-ready nature and it is possible to have materials which can be either polar or non-polar depending upon their surroundings. Chemists have also produced a variety of substances (known as wetting agents) that are simultaneously polar and non-polar. But as a first approximation we can divide liquids into polar and non-polar groups.*

"*The existence of cohesive forces (either polar or non-polar) in liquids is the reason why liquids can form drops. The outermost layer of the liquid is always pulled inwards by the cohesive forces because this outermost layer is, of course, not acted upon by any compensating forces on the outside; the liquid behaves as though it were enclosed in a rubber bag kept in a state of tension. These cohesive forces remain when the liquid solidifies, so that solids can also be classified into polar and non-polar groups. Metals are held together by non-polar forces of a special kind; wood, paper and glass, on the other hand, are polar solids. This is shown rather strikingly by a simple experiment. Some water is put into a glass tumbler and then toluene or petrol or benzene is poured on to the water. The non-polar liquid will not, of course, mix with the water, which is strongly polar. Strips of metal, bakelite and glass are then stood vertically in the glass tumbler. The metal and bakelite pull down the non-polar liquid, for which thay have an affinity, while the glass, which is a polar material pulls up the water into the non-polar liquid.*

"Why are polar and non-polar materials antagonistic? *Since both polar and non-polar materials are both subjected to cohesive or attractive forces, it is at first difficult to see why they should dislike each other. The answer is that the polar forces in liquids are usually much stronger than the cohesive forces in non-polar liquids. If we pour a non-polar liquid into water, the attraction between the water molecules is sufficiently strong to squeeze out the non-polar liquid, which thus finds itself separated out from the water molecules.*

"Consequences of the antagonism: *It is pretty clear then that it will not be much use trying to solder metals with a polar liquid afterwards solidified to a polar solid; nor will it be any good trying to glue wood with a non-polar liquid afterwards solidified to a non-polar solid. We must use non-polar adhesives for metals and polar adhesives for wood. We should expect,*

therefore, that hydrocarbons like rubber, paraffin wax, poly-styrene and naphtalene, and also molten metals, would stick well to clean metals but poorly to wood. Conversely, water (frozen to ice), thermo-setting phenol-formaldehyde resins and urea-formaldehyde resins before they have reached their final hardened state should stick well to wood but poorly to clean metals.

"Shrinkage stress: *While compatability between the adhesive and the solid surface is an essential and necessary condition for good adhesion it is not in itself a sufficient one. The solidification of the adhesive is nearly always accompanied by a change in volume which will impose strains which will weaken and may even cause fracture of the joint. This is probably why urea-formaldehyde resins, for instance, stick well to glass until they are hardened. A good adhesive must therefore possess not only good intrinsic adhesion but must also have mechanical properties such that no strong residual forces are produced at the interface when solidification takes place.*

"Mechanical adhesion: *So far we have regarded adhesion as a specific effect due to the cohesive forces emanating from materials, but we must not rule out the possibility of the existence also of some mechanical adhesion due to dovetailing and inter-locking between the adhesive and a rough surface. But the strong joints obtained with smooth surfaces and the poor joints obtained with polar glues to wood after it had been made non-polar seem to show that specific adhesion is usually far more important than mechanical adhesion. It is sometimes adduced as evidence of the existence of mechanical adhesion that by roughening a surface it is possible to make a poor joint (such as that between a polar adherend and a non-polar adhesive) into a good one; but it must be remembered that such roughening greatly increases the area of the surface available for adhesion. Measurements show that the surface area can easily be increased twenty times by sand blasting a polished metal surface. Also the effect of such roughening should increase the tensile strength of joints because it gives to the surface components in the direction of the tensile load; thus instead of a pure tensile load on the joint we get some shear loading, and shear loading because of the short range of the cohesive forces is very much 'kinder' to glued joints than pure tension.*

"The conclusion is, however, that though there is some truth

in the popular conception that glue sticks by forming small 'keys' in the physical structure of the materials, the strength of a joint lies chiefly in the molecular attraction between the substances joined."

It will be noted that Butterworth refers several times in his paper to the work of McBain and Lee. Readers who wish to know more about "Adhesives and Adhesive Action" cannot do better than read the interesting chapter under this heading by W. McBain, F.R.S., and W. B. Lee, Ph.D., which is to be found in Appendix III of the third and final *Report of the Adhesive Research Committee*, issued by the Department of Scientific and Industrial Research.

This same Report gives valuable information on "Mechanical Tests of Adhesives for Timber", by W. D. Douglas, F.R.C., Sc.I., and C. B. Pettifor, B.Sc., and results of "Investigations on Gelatin", by S. B. Schryver, D.Sc., Ph.D., F.R.S.

Another point to remember about wood adhesives of all kinds is that it is no use blaming them for poor results if the joints are not machined accurately. Owing to the inability of ordinary synthetic-resin adhesives to stick unless there is precision machining and complete freedom from gaps, the makers of these synthetic adhesives have introduced special "gap-filling" synthetic-resin adhesives and many people now think that all adhesives other than gap-filling resins are non-gap-filling. This is not so; all the older adhesives are just as much gap-filling as the gap-filling synthetic resins. Nevertheless, whilst they will flow into and fill small gaps and exert some adhesion too, they will not develop their full strength whilst so doing, and they should not be used to compensate for inaccurate machining. All adhesives only develop their full strength when the molecules of the two surfaces to be joined are in close proximity.

Chapter 2

SELECTING THE RIGHT ADHESIVE

THE summary chart of the properties and characteristics of wood adhesives which is given on pages 162-163 should assist in the selection of the right adhesive for any particular purpose. The final selection is dictated usually by cost in relation to the special qualities required of the adhesive.

All those described in this book will give strong "dry glue" joints on the great majority of timbers, but they vary greatly in water and heat resistance; ease of mixing; ease and method of application; heat required in preparation, application and pressing; workshop temperature requirement; working life; cost and complexity of apparatus required; pressure required; setting time; tendency to stain the wood; effect on woodworking machines; effect on polishing processes; effect on the operator's skin.

It is no use spending heavily on plant, material or labour to obtain some quality that is of no advantage for the particular work; neither is it worth paying to obviate some tendency that is no disadvantage in a given process.

By taking into consideration the average spreads of the various types of adhesives given in the chart and by correlating them to the prices per pound, hundredweight or ton from the manufacturer, some idea will be obtained of the relative costs; but it will only be some idea. To arrive at the true figure, the following points must also be taken into consideration:—

(1) What is the relative amount of labour, time and degree of skill required in preparing the different varieties of adhesive?

(2) Is the provision of heat, with its attendant cost, necessary

    (a) in the preparation,

    (b) in the mixing,

    (c) during the working life, and

    (d) in the setting process?

(3) Will the adhesive entail unusual preparation or drying of the timber or veneer and will special heating or cooling and air-conditioning of the whole or a part of the factory be necessary, justified and practical?

(4) Is expensive equipment required for the mixing, application or pressing? Is it justified?

(5) Will the proposed adhesive slow down or speed up the gluing process in the factory?

(6) If it will speed the process, will it involve increased cost through more highly skilled labour, or more expensive machines or precision in machining? Will such additional cost be repaid by the increase in output?

(7) Will the adhesive add to or subtract from the difficulties or labour of other stages of the manufacturing process and can the required conditions be made available in the factory (or in some cases on a building site)?

The chapters which follow will assist in arriving at the correct answers to these questions, in relation to individual problems.

When it has been decided which adhesive will best suit a particular purpose, it should not be thought that it is sufficient to buy the best grade and then hand it over to an incompetent person to prepare. This is an expensive, though quite common, practice. Even the preparation of a ready-mixed adhesive is as much a skilled operation as the making of pastry, and results obtained by different operators from the same recipes differ just as widely.

Assuming that a ready-mixed formula is being used, in order to obtain the best results ensure that the "cook" reads, understands and carries out the manufacturer's instructions.

Some buyers will not consider jelly and liquid glues or ready-mixed caseins or resin films because they cost more, but it may be only the first cost, not the "user cost", that is increased. Naturally, each successive stage of preparation which the manufacturer undertakes for the consumer increases the purchase price. Before, however, it is decided that it is uneconomic to purchase adhesives prepared ready for use, the labour and cost of operations and the risk of errors thus saved in the factory should be weighed up.

There is a considerable difference of opinion as to the merits of hot versus cold-press methods of veneering, and many factors

must be taken into consideration before deciding which is to be adopted. Hot pressing speeds up production and conserves factory space. It is ideal where maximum mass-production of standard-sized panels is the aim. The first cost is heavier than for the cold press and the repair cost is higher. The cost of supplying the heat must also be considered, as must the employment of more highly skilled labour both in the pressing and in the preparation stages. Cold pressing takes longer, uses more space but simpler apparatus, and thus obviates heating costs. It is performed at lower pressures and in consequence is not as likely to show up core defects. It is a much more suitable process for building-site work.

The details given in the chapters on the various adhesives will show that, broadly speaking, the phenolic-resin, the blood-albumin, the vegetable protein and the vegetable-starch adhesives are the "primary" adhesives for facing or for the assembly of plywood, and the urea-resin, the casein and the animal glues are the general-purpose, assembly, jointing or veneering adhesives —that is, the "secondary" adhesives.

Chapter 3

MOISTURE RESISTANCE

FOR some uses high or complete moisture resistance is the most important quality of an adhesive, but it has to be paid for either in higher cost of adhesive, more complex gluing plant and operation or greater precision and control of the general manufacturing process. Sometimes it involves all these disadvantages. It is no use, therefore, paying for this quality for making, say, furniture or interior woodwork, where the polish or paint finish provides all the protection necessary for the adhesive. It is a mistake to describe any adhesive as waterproof. None is; moisture can pass through all of them, but in some cases without weakening them materially.

The most completely water-resistant group of adhesives are the synthetic resins, particularly the phenol-formaldehydes and the melamines; the next highest resistant are the blood albumins; and then, a very bad third, are some of the casein mixes. They are run very close by special animal glues to which oxalic acid and paraformaldehyde have been added.

The most important moisture-resistance tests for adhesives for exterior use are:

(a) frequently alternating cycles of low and high humid atmospheric conditions;

(b) frequent alternative cycles of soaking and drying;

(c) continuous long-term humidity;

(d) continuous long-term soaking.

Adhesives fail under changing moisture conditions through three main causes:

(1) Chemical hydrolysis of the adhesive itself.

(2) Conditions conducive to destruction of the adhesive by micro-organisms.

(3) The weakening of the adhesive during its wet condition, causing it to fail to stand up to the increased mechanical stresses set up by the changes of dimension of the wood under the varying moisture contents.

Point (3) is not sufficiently appreciated. It very often brings about first failure of joints made with adhesives which otherwise would fail eventually from points (1) or (2).

The blood albumins will stand continuous immersion as well as most of the synthetic resins, but because they lose strength temporarily when wet, they fail through the continuous mechanical stresses set up by the wood under alternating wet or dry or humid and dry conditions.

It is here that some synthetic resins score; their wet strength is so near akin to their dry that they seem able to stand the changing wood stresses indefinitely, as well as being resistant to hydrolysis and micro-organisms. The U.S. Forest Products Laboratory has carried out a series of extremely severe and controlled exposure tests of four different types on entirely unprotected birch plywood, glued with synthetic resins, blood-albumin and casein cements.

By kind permission of the Laboratory, the following details are given. Five synthetic resins were used, of which four (P–1, P–2, P–3 and P–4) were reported to be of the phenol-aldehyde type and one (V–1) a vinyl ester.

The birch veneers were selected by the Laboratory and sent to the synthetic resin manufacturers for gluing under the conditions that they each believed most favourable for their particular product.

Insufficient quantities of ply glued with P–2 were available for all four exposure tests, so it was used on the soaking-drying test, which was considered the most important. Its omission from the other three tests necessitated the use of the two sets of control averages shown in the sixth column of Table 1, given in the appendix to this chapter (page 37).

The casein and the blood-albumin bonded panels were glued under favourable conditions at the Laboratory, in accordance with the U.S. Forest Products Laboratory's formulæ. Formula No. 11, which is given in the appendix to the chapter on caseins, was the one chosen for the casein tests and the paraformaldehyde-blood-glue mix formula that was used is given in the appendix to the chapter on blood albumins.

The report goes on to say:

"*The procedure after gluing was identical whether the panels were glued at the laboratory or received from the manufacturers.*

All panels were conditioned to approximate equilibrium in a room at 65 per cent. relative humidity and then cut into standard plywood test specimens. Each panel yielded 30 test specimens, giving a total of 600 specimens for each glue. Five specimens from each panel were tested dry and five were tested wet after soaking for 48 hours in water at room temperatures. If the test values from any panel were low and erratic, that panel was eliminated from further tests. After eliminating defective panels, the dry test values of the specimens from the remaining panels were averaged for each glue and these averages were used as a basis of comparison throughout the tests. The same procedure was carried out to obtain the wet test values, although these were not used as a base for comparison. For each glue, the specimens were then mixed together to ensure random sampling and divided into four groups of 75 specimens each, one group for each of the following tests:

(1) *Soaked continuously in water at room temperatures.*

(2) *Exposed continuously to 97 per cent. relative humidity at 80° F.[1]*

(3) *Exposed to a repeating cycle consisting of 2 days' soaking in water at room temperatures followed by drying for 12 days in 30 per cent. relative humidity at 80° F.[1]*

(4) *Exposed to a repeating cycle consisting of 2 weeks in 97 per cent, relative humidity at 80° F.[1] followed by 2 weeks in 30 per cent. relative humidity at 80° F.[1]*

"*From each group, five specimens were tested at intervals of 2½, 5, 8, 12, 18, 24, 30, 36, 42 and 48 months. For the cyclic exposures, Nos. 3 and 4, the testing was done at the end of the 'dry half' of the cycle. Specimens from exposure No. 1 were tested wet as soon as possible after removal from soaking and specimens from exposure No. 2 were tested promptly upon removal from 97 per cent. relative humidity. The test value for each five specimens were averaged and the averages are shown in Table 1.[2]*

"*The tests are still in progress while this report is being prepared, with sufficient specimens remaining to continue the study through the 60th month.*

"*In preparing the charts, all successive average values were plotted as percentages of the original average value from the*

[1] 27° C.

[2] See Appendix to this chapter, p. 37.

dry tests. This procedure permitted easier comparison of the rates of failure, since all lines then start from the same origin of 100. Percentage of wood failure was based on a visual inspection of the broken glue joint and an estimation of how much of the failure occurred in the wood as compared to the failure in the glue-line itself. The amount of wood failure was expressed in percentage of the total joint area, and in the charts, therefore, the wood failures were plotted as recorded.

In these tests, the specimens were unprotected, the dimensions were small, and the specimens spaced on rods to permit circulation of water or air during the exposure cycles. The wood, therefore, probably attained approximate equilibrium with the exposure conditions at each period of the exposure cycle and the stresses developed on the glue joints approached the maximum that could be expected under the conditions prevailing.

Results

"One of the first impressions gained in this study was the importance of the amount of wood failure developed when testing the joints. With the more commonly used woodworking glues the percentage of wood failure was low after any appreciable exposure to moisture. With many of the artificial resin glues, however, the amount of wood failure developed usually exceeded 50 per cent. and often approached 100 per cent. For this reason it seems important to include wood failure values in tables and charts if an accurate picture of the quality of joint is to be presented. If the percentage of wood failure developed on test approaches 100, obviously the strength of the wood in shear rather than the strength of the bond determines the test value obtained.

"TEST No. 1. CONTINUOUS SOAKING IN WATER. The wet test values (Table 1) [1] indicate primarily the degree to which the joints are weakened by early softening of the glue, particularly if low strength values are combined with low wood failures. When long continued, however, soaking in water serves as an approximate measure of the rate or the degree to which the joints weaken by the hydrolysis of the glue itself.

"Conforming to the results of previous experiments, the casein glue hydrolysed at such a rate that all the joints had failed completely at the end of 25 months and at the end of 18 months

[1] See Appendix to this chapter, p. 37.

the average test value was nearly down to zero (Table 1 and Fig. 1).[1] This was a casein glue comparatively low in alkalinity. A casein glue high in alkalinity would be expected to hydrolyse more rapidly.

"*As might be expected from a consideration of their chemical composition, the artificial resin glues used in these tests did not show a tendency to weaken when soaked continuously in water. If that tendency is present at all, it is masked by the more rapid weakening of the wood itself. When the average figures are plotted (Fig. 1)[1] they show a gradual decrease in strength, but the average percentage of wood failure at the end of four years is some 72 per cent., an amount approximately equal to the average wood failure developed in the original dry tests. The vinyl resin is not included in the averages plotted on the chart, but, like the other artificial resins in this respect, it did not appear to weaken any more rapidly than the wood when soaked continuously in water.*

"*The artificial resin glues, however, are not unique in their ability to resist exposure of this type. The paraformaldehyde-blood-albumin glue applied by the hot-pressing method does not hydrolyse at all rapidly. So far as resistance to continuous soaking is concerned, specimens glued with hot-pressed para-formaldehyde-blood glue performed as well as the specimens glued with artificial resins.*

"TEST NO. 2. CONTINUOUS EXPOSURE TO 97 PER CENT. RELA-TIVE HUMIDITY. *The conditions of this exposure are favourable to the development of fungi. Under these conditions, moulds will attack an unprotected protein glue rapidly and wood-destroying fungi will cause rotting of non-durable and unprotected wood specimens.*

"*The casein glue used contained no chemicals of sufficient toxicity to retard mould growth and the joints made with casein glue failed rapidly, dropping to 19 per cent. of their original strength after $2\frac{1}{2}$ months (Fig. 2).[1] After 5 months, the casein joints were so weak that they broke in test before a measurable load could be applied. All specimens glued with casein glue had failed completely by the end of 12 months.*

"*The artificial resin glues of the phenolic type appear to be resistant to attack by micro-organisms. The strength test-values decreased slowly, but the percentage of wood failure increased,*

[1] See Appendix to this chapter, pp. 37 and 38.

indicating that the wood was failing more rapidly than the glue and not establishing clearly whether the glue itself had been weakened. At the end of 18 *months, visual evidence of rot could be detected in the specimens glued with phenolic resins and by* 36 *to* 48 *months the wood had rotted to a very marked degree. Apparently, then, the phenolic glues themselves were not attacked by micro-organisms, but the presence of a phenolic glue-line did not afford protection sufficient to prevent rot in 3-ply, $\frac{3}{16}$-in. birch plywood.*

"The resistance of the vinyl-resin joints was not clearly established by these tests. At the end of 48 *months the test values had decreased to some* 55 *per cent. of their original value. The specimens were clearly rotted, but the percentage of wood failure did not increase to the extent that might have been expected from the amount of rot present.*

"Against mould action, the resistance of the hot-pressed paraformaldehyde-blood joints appeared to be more than equal to the resistance of yellow birch to wood-destroying fungi. The fact that 100 *per cent. wood failure was developed in all tests of blood-glue joints in this exposure at the* 5th *month and thereafter indicated that the decrease in test values was due to a weakening of the wood rather than failure in the glue itself. The specimens were not examined microscopically for evidence of wood-destroying organisms nor were cultures made, but visual evidence of rot could be detected by the* 18th *month and rotting was very marked by the end of three years. In tests of this type, additional information on the resistance of the glue-line itself might have been obtained if tests had also been carried out with a more durable species of wood, such as the heartwood of southern cypress, redwood, or western red cedar.*

"Two conclusions from this test should be emphasised:

(1) *The resistance of the phenolic resins to attack by micro-organisms appeared entirely satisfactory but not unique, for hot-pressed blood glues (that contained paraformalde-hyde) also proved resistant to this type of exposure.*

(2) *The presence of a glue-line resistant to fungi did not prevent rotting of the plywood. The production of ply-wood resistant to this type of exposure requires a glue resistant to fungi and a species of wood resistant to wood destroyers, or a treatment of the wood with effective preservatives.*

3   33

"TEST No. 3. EXPOSURE TO A REPEATING CYCLE THAT CON-
SISTED OF SOAKING IN WATER FOR 2 DAYS FOLLOWED BY DRYING
FOR 12 DAYS IN 30 PER CENT. RELATIVE HUMIDITY. *This ex-
posure, which approached most nearly to exterior exposure
conditions, was one that brought out most clearly the superiority
of the hot-pressed phenolic-resin glues over the other glues
used in these experiments. The casein-glue joints had lost some-
thing over 40 per cent. of their strength by the first test period
of 2½ months (Fig. 3)* [1] *and had failed almost completely at the
end of 18 months, although the last remaining specimens did
not fall apart until the 30th month. Compared with other similar
tests on casein glues, these joints were more than usually durable.
Similar exposures in other tests have caused casein joints to
fail completely as early as three months.*

"*At the end of four years, joints made with paraformaldehyde
blood glue still retained something over 20 per cent. of their
original dry strength, but the test values showed in general a
steady and consistent decrease. The average percentage of wood
failure never exceeded 44 per cent. and, after the 18th month, no
wood failure could be detected by visual inspection of the broken
specimens. Decreasing test values and no wood failure indicates
a weakening of the glue-line. The trend at the 48th month,
therefore, indicated that the blood-glue joints were approaching
ultimate failure. Similar tests, carried out previously on blood-
albumin joints, resulted in total failures at from 25 to 30 months.*

"*On the other hand, joints made with phenolic resins have
retained an average of 60 per cent. of their original dry strength
through four years of alternate soaking and drying. More
important, the average percentage of wood failure in the 4-
year specimens was some 53 per cent. The average test values
appeared to be decreasing, but the fact that a high percentage
of wood failure continued to be developed indicated that the
severe exposure may have been weakening the wood. At the
48th month there was no indication that the joints would fail
more rapidly than the wood itself. These results lend encourage-
ment to the hope that glues may now be available that can
withstand exposures as severe as can be resisted by the wood.*

"*In this very severe exposure, the vinyl-ester glue-line (Table
1)* [1] *appeared to lack the necessary strength when wet and the
joints weakened at a rate approximating that for casein-glue joints.*

[1] See Appendix to this chapter, pp. 37 and 38.

"TEST NO. 4. EXPOSURE TO A REPEATING CYCLE OF 2 WEEKS'
EXPOSURE TO 97 PER CENT. RELATIVE HUMIDITY FOLLOWED BY
2 WEEKS' EXPOSURE TO 30 PER CENT. RELATIVE HUMIDITY.
*From the nature and rate of failure it appears that the primary
cause of failure in this test cycle was attack by micro-organisms.
The casein joints failed more rapidly than they did in the soaking-
drying test (Table 1),[1] yet it was improbable that the mechanical
stresses involved were more severe. The exposure serves to
illustrate the probable performance of joints with the different
glues exposed in service to dampness and warmth for a period
followed by a period of dryness.*

"*As in the tests involving continuous exposure to high humidity,
the resistance of paraformaldehyde-blood glue was satisfactory.
At the end of four years the average test value was some 68
per cent. of the original dry test value and the percentage of
wood failure was over 50 per cent. (Fig. 4).[1] Slight evidence
of wood rot could be detected by visual inspection, indicating
that the decrease in test values was due, at least in part, to a
loss of mechanical strength of the wood.*

"*As might have been expected from their behaviour in other
tests, phenolic-resin joints were not seriously affected by this
exposure. A relatively high percentage of wood failure was
developed at each test throughout the four years. Whatever the
decrease in average test values, it appeared to be due to a de-
crease in the strength of the wood rather than failure in the
glue. Visible signs of wood rot could be detected in some of the
specimens, indicating again that a glue-line resistant to fungi
does not offer sufficient protection to the wood against fungus
attack.*

"*The joints made with the vinyl-ester did not appear to be
affected by mould and they withstood this exposure much better
than they did the soaking and drying cycles.*

Summary

"*Joints made with different artificial resin glues of the phenolic
type have satisfactorily withstood four years of exposure to
extremely severe test conditions. These glues did not appear
to soften or hydrolyse on continuous soaking in water and the
joints were not affected by moulds, although the presence of the*

[1] See Appendix to this chapter. pp. 37 and 38.

mould-resistant glue-line did not protect the wood itself from the action of wood-destroying fungi. After four years of soaking and drying the specimens still developed a high percentage of wood failure in test.

"The one vinyl-ester included appeared to be sufficiently resistant to hydrolysis and to mould attack, but lacked the strength required to withstand stresses caused by repeated wetting and drying.

"Previous experiments with the older woodworking glues were confirmed in that:

(1) *the blood-glue formula containing paraformaldehyde was sufficiently resistant to moulds and hydrolysis, but it lacked the strength to withstand indefinitely the mechanical stresses set up by repeated wetting and drying;*

(2) *casein glues were readily subject to failure from hydrolysis, mould action, and mechanical stresses when the glue was softened by absorption of water."*

Appendix to Chapter 3

Table 1. A summary of average test values obtained upon subjecting specimens of birch plywood to different conditions of exposure

Time of Exposure	Resin P—1	Resin P—2	Resin P—3	Resin P—4	Average of P—1, 2, 3 & 4	Resin V—I	Blood	Casein
Test values[1]								
None, dry controls	473·77	435·100	590·74	479·86	{514·79[2] / 494·84[3]	404·27	447·48	418·5
48 hours wet[4]	460·73	329·92	443·67	375·65	{426·68[2] / 402·74[3]	275·5	379·51	265·2
Soaked continuously in water:								
2½ months	398·90		456·62	350·44	401·65	246·6	368·28	196·0
5 ,,	421·100		412·74	375·75	402·83	239·8	344·26	151·0
8 ,,	327·69		387·60	352·14	355·48	214·2	341·31	126·2
12 ,,	396·73		399·22	301·58	365·51	251·38	305·82	49·0
18 ,,	399·100		332·90	331·45	354·78	223·52	305·74	8·0
24 ,,	278·67		284·34	243·46	268·49	183·24	307·66	0·0
30 ,,	304·72		277·70	278·31	286·58	189·20	238·62	0(25)
36 ,,	291·100		268·58	242·68	267·75	179·42	232·90	
42 ,,	233·98		228·100	242·86	234·95	154·64	241·100	
48 ,,	231·94		229·73	157·48	206·72	117·64	211·93	
Exposed continuously to 97 per cent. relative humidity:								
2½ months	356·45		414·96	360·65	377·69	277·5	397·90	81·6
5 ,,	450·98		464·100	354·60	423·86	263·12	340·100	0·0
8 ,,	328·99	•	463·100	342·44	378·81	223·0	295·100	0·0
12 ,,	335·80		477·98	332·63	381·80	301·33[5]	251·100	0(12)
18 ,,	423·100[5]		446·100[5]	294·62[5]	387·87	262·40	256·100[5]	
24 ,	339·73		448·100	290·33	359·69	258·22	215·100	
30 ,,	319·100		372·82	242·99	311·94	234·2	158·100	
36 ,,	340·100		434·89	275·100	350·96	245·42[6]	162·100[6]	
42 ,,	212·100[6]		382·96	194·90[6]	263·96	237·18	131·100	
48 ,,	353·100		326·100[6]	180·100	286·100	223·37	91·100	
Exposed to a repeating cycle : 2 days soaking followed by 12 days drying in 30 per cent. relative humidity:								
2½ months	477·97	346·99	448·24	412·100	421·80	211·1	328·20	237·0
5 ,,	429·74	397·98	487·32	411·46	431·63	90·2	397·0	204·0
8 ,,	524·89	427·72	512·83	433·32	474·69	130·28	407·29	93·0
12 ,,	495·60	382·99	483·47	351·61	428·67	58·0	298·0	43·0
18 ,,	493·76	402·80	427·82	400·46	431·71	28·0	323·40	0·0
24 ,,	438·92	362·46	446·49	437·78	421·66	0(19)	233·0	42·0
30 ,,	476·66	394·36	468·54	273·10	403·42		270·0	0(25)
36 ,,	348·99	279·80	312·68	205·14	286·65		129·0	
42 ,,	392·46	370·78	490·20	198·3	362·37		135·0	
48 ,,	345·28	291·65	368·91	187·28	298·53		105·0	
Exposed to a repeating cycle 2 weeks in 97 per cent. relative humidity followed by 2 weeks in 30 per cent. relative humidity:								
2½ months	577·77		553·70	395·47	508·65	270·5	383·56	267·2
5 ,,	497·93		530·86	370·14	466·64	250·4	356·99	251·0
8 ,,	465·89		451·79	367·8	428·59	204·2	356·98	50·2
12 ,,	530·92		512·46	408·66	483·68	162·11	332·36	0(12)
18 ,,	420·94		465·98	372·28	419·73	226·8	359·82	
24 ,,	401·56		466·71	346·21	404·49	52·0	330·73	
30 ,,	541·77		489·59	354·22	461·53	64·10	314·30	
36 ,,	420·88		520·95	306·15	415·66	77·25	279·59	
42 ,,	537·70		453·41	344·31	445·47	120·8	292·34	
48 ,,	393·100[5]		489·89[5]	260·05	387·63	92·6	305·57[5]	

[1] First figure in each pair of values is joint strength in pounds per square inch, the second figure is wood failure in per cent. Each value is an average of 5 specimens figure in parenthesis represents time in months when last specimen failed.

[2] Averages of P—1, 3 and 4.

[3] Averages of P—1, 2, 3 and 4.

[4] Test wet after soaking in water at room temperature for 48 hours.

[5] Slight evidence of wood rot.

[6] Marked evidence of wood rot.

37
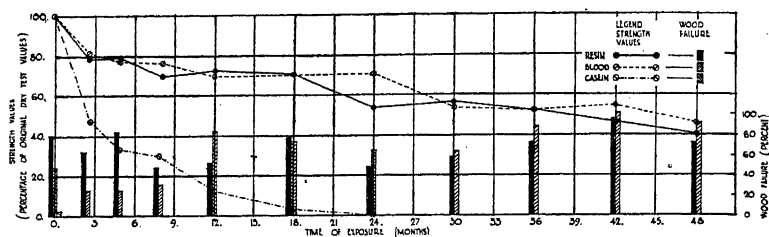
FIG. 1. RATE OF DETERIORATION OF GLUE JOINTS WHEN SOAKED CONTINUOUSLY IN WATER
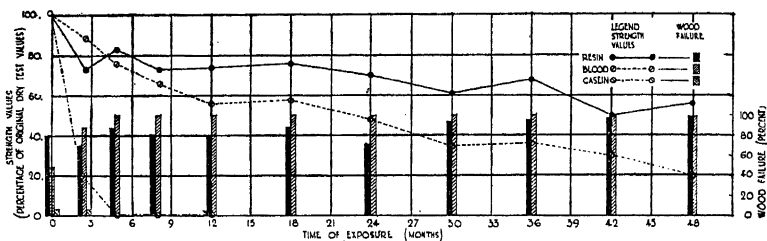
FIG. 2. RATE OF DETERIORATION OF GLUE JOINTS WHEN EXPOSED CONTINUOUSLY TO 97 PER CENT. RELATIVE HUMIDITY
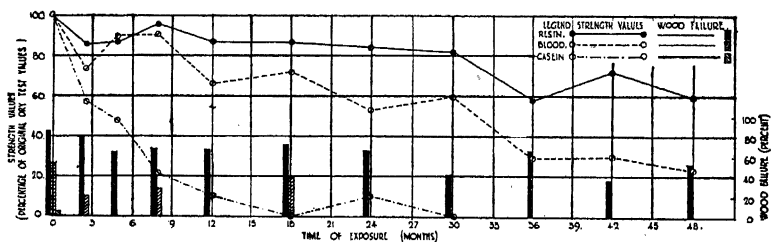
FIG. 3. RATE OF DETERIORATION OF GLUE JOINTS WHEN EXPOSED TO A REPEATING CYCLE OF 2 DAYS' SOAKING FOLLOWED BY 12 DAYS' DRYING
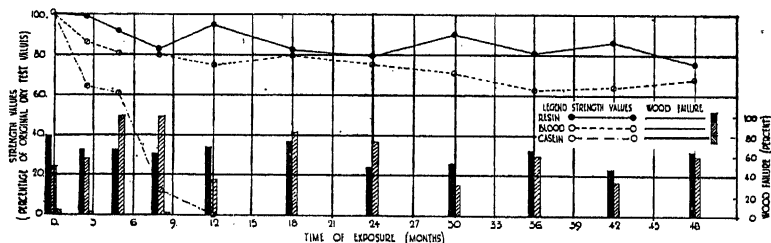
FIG. 4. RATE OF DETERIORATION OF GLUE JOINTS WHEN EXPOSED TO A REPEATING CYCLE OF 2 WEEKS IN 97 PER CENT. RELATIVE HUMIDITY FOLLOWED BY 2 WEEKS IN 30 PER CENT. RELATIVE HUMIDITY

38

Chapter 4

SOME COMMON CAUSES OF FAILURE IN ADHESION

As the different chapters of this book describe, faulty glue joints and defects consequent upon faulty gluing may arise from many different causes, and even a particular defect may be caused by varying conditions in different factories.

Some of the most general forms of failure and the commonest reasons for them are summarised below, but it is always dangerous to jump to conclusions based on inspection of one or a few defective samples. When suspicions are aroused that all is not well with the gluing, a thorough check on the process adopted should be carried out. It may well be found then that the fault is due to a combination of circumstances, all of which must be considered before corrective measures can be put in hand.

(1) Open glue joints may be caused by:

(a) Imperfect machining preventing complete contact in the whole length or breadth of joints.

(b) Pieces of warped stock forced together under pressure.

(c) Poorly fitting joints.

(d) Excessive moisture in wood, or occasionally excessive drying.

(e) Stresses due to non-uniform moisture content of wood.

(f) Varying absorption of two different varieties of wood.

(g) Uneven glue spread.

(h) Unevenness of press plates in the case of veneering or plywood manufacture.

(j) Glue dried or jellied before pressing.

(k) Insufficient pressure or pressure over too short a period.

(l) Uneven pressure of press or clamps.

(m) Uneven thickness of core in the case of veneered stock.

(2) Close but weak joints may be caused by:

(a) Poor quality adhesive.

(b) Use of too thick or too thin a mixture.

(c) Insufficient adhesive being used.

(d) Animal glue being overcooked or cooked at too high a temperature.

(e) The adhesive being only partially dissolved.

(f) The adhesive having been allowed to froth in the mixing.

(g) Pressure being applied before the adhesive has thickened sufficiently or after it has commenced to gel.

(h) Too great or too long a pressure.

(j) Insufficient pressure or pressure exerted over too short a period.

(k) Grease, dust or other foreign matter being on the gluing surfaces of the wood.

(l) Excessive moisture in or occasionally excessive drying of the wood.

(m) Exposure of non-moisture-resistant adhesives to moisture conditions.

(n) Butt joint weakness (See Chapter 5: "The Preparation of Wood for Gluing").

(3) Blisters under veneers may be caused by:

(a) Poor-quality core containing defects such as knots.

(b) Uneven thicknesses of core.

(c) Uneven cutting of veneer (rare).

(d) Insufficient conditioning and "flattening" of veneers.

(e) Steam pockets (in hot pressing).

(f) Overlap joints of veneer.

(g) Worn or damaged cauls.

(h) Nearly all the causes listed under (1) and (2).

(4) Warping may be caused by:

(a) Gluing together pieces of wood of varying or incorrect moisture content.

(b) Gluing together pieces of wood of varying species, strength and porosity.

(c) Adding too much moisture in gluing.

(*d*) Improper construction, such as:
  (i) Veneering the face but not the back of a panel.
  (ii) Veneering both sides, but not equalising the pull as a result of using veneers of entirely different strength or thickness.
  (iii) Polishing, painting or varnishing a panel face without sealing the back.
(*e*) Bending in the clamps or press.
(*f*) Using undue force to make joints in faultily machined or already warped material.
(*g*) Using poorly constructed plywood as a base for veneering.

(5) Various surface defects and their probable causes.
  (*a*) Sunken joints due to machining before the adhesive has dried out and finished contracting.
  (*b*) Checks due to:
    (i) Wood being glued at too high a moisture content.
    (ii) Adding too much moisture in gluing.
    (iii) Finishing before wood or veneer has dried to correct moisture content.
    (iv) Improper construction (see 4, *d*).
  (*c*) Wavy or corrugated veneered surfaces, due to:
    (i) The use of cores of varying species.
    (ii) Hard and soft grain cores, such as Douglas fir.
    (iii) Cores having planer-marked surfaces.
    (iv) Cores of varying thickness.
    (v) Cores of varying moisture content.
    (vi) The commencement of delamination as a result of exposing non-moisture-resistant adhesives to moisture conditions.

(6) Staining due to:
  (*a*) Alkaline adhesives.
  (*b*) Veneer glued when too wet.
  (*c*) Veneer left under pressure too long.
  (*d*) Veneer placed under excessive pressure.
  (*e*) Use of thin veneer with dark glue.
  (*f*) Use of porous or exceptionally thin veneer without sizing before gluing.

THE PREPARATION OF WOOD FOR GLUING

I F the timber used is not seasoned properly, permanently good joints cannot result. Quite apart from the inevitable shrinkage and distortion consequent upon using unseasoned timber, there cannot be full adhesive strength in the joint if the cavities into which the glue is to be forced are already filled with sap, which dilutes the glue and helps to cause starved joints.

Moreover, sap in contact with glue sets up a condition conducive to the growth of moulds, which weaken and eventually destroy most adhesives. The moisture content of wood that is to be glued should never be more than 20 per cent. and need rarely be less than 10 per cent.

The Drying of Timber and Veneer

With some adhesives, notably the synthetic resins, much closer control is necessary and with some varieties satisfactory joints cannot be guaranteed if the wood moisture content exceeds 10 per cent. Kilning timber down to a certain moisture content is useless unless steps are taken to keep it at that figure subsequently. Generally it is advisable to kiln to 2 per cent. lower moisture content than the final figure desired, because the gluing operation puts back a certain amount of water into the wood. This figure is usually in the region of 2 per cent., but varies according to the type of adhesive and closeness of joints or relationship of veneer to thickness of core.

Drying of veneer before gluing must be varied according to the ultimate purpose. Thin veneer for furniture requires much lower moisture content than, say, veneer for water-resistant plywood used in shipbuilding or aircraft work. It is never practical to dry veneer to less than 2 per cent. or 3 per cent. moisture content, or it becomes too brittle to handle in the gluing operation. A moisture content of 5 per cent. or 6 per cent. is a satisfactory figure for furniture veneer, but the veneered

stock will contain much higher moisture content after gluing and requires a reconditioning period before polishing. Dry veneers stain less than wet ones when glued with those adhesives that have a tendency to stain.

Veneers glued at a moisture content of 10 per cent. to 20 per cent. have a higher strength value, when tested wet, than those glued with a low moisture content.

Kilns are sometimes situated outside the main building of the factory and unfortunately stacks of timber that have been taken from the kiln late in the day are sometimes left out all night. Usually they are covered by a tarpaulin, but this, although shielding them from rain, does nothing to protect them from picking up atmospheric moisture, to which they are particularly prone in their warm, dry condition.

The manufacturer who subsequently receives complaints of unsatisfactory products would be surprised and perhaps incredulous to learn the true moisture content of his previously kiln-dried wood at the time of gluing.

Hygrometers and kiln charts are excellent, but wet and dry bulb thermometers are nearly as important in the main factory as in the kiln.

To obtain the best results there is no doubt that the woodworking factory should be air-conditioned from the kilning stage up to the despatch of the finished article. For interior woodwork, such as furniture, which is more and more commonly exposed to the dry heat of central-heated homes, air-conditioning in the factory is essential if the finished product is to give satisfaction.

Not only "open joints" and wavy veneers but polishing faults too are usually due to damp and cold during the manufacturing processes. Even where fully controlled air-conditioning is not possible, recourse should never be had to the false economy of shutting off all heat at night and over week-ends in winter or of allowing broken windows or ill-fitting doors to remain unrepaired. Adhesives, like elephants, never forget.

MACHINING TIMBER FOR GLUING

Careful machining is essential in the preparing of wood for gluing. Surfaces must be smooth, even and flat. For these reasons it is advisable that the gluing operation should follow closely on the machining. In order to obtain normal joint strength, the

surfaces to be joined must be prepared with sharp tools, otherwise some polishing of the wood results and this prevents easy penetration of the glue. Sawn surfaces are rougher than those made by the cutting heads of jointers, planers, etc., but certain precision saws, such as straight-line-edgers, have been brought to such a pitch of perfection now that it is quite practicable to joint stock straight off them, and the saving of timber and labour by so doing is appreciable.

Square, square tongued-and-grooved, circular tongued-and-grooved and dovetailed are the commonest types of edge joints used in width gluing—i.e. edge-jointing boards. In many cases the tongueing operations are unnecessary and serve no useful purpose, besides wasting much timber. Plain square-edged side-grain joints are as strong or stronger than most commercial timbers, and therefore the extra glue surfaces provided by the tongues and grooves are useless. Tongued-and-grooved and dovetailed side-joints are more difficult to fit accurately than plain ones and they dry more slowly. When they are not fitted accurately, they are weaker than good fitting plain ones. Their most valuable function is to provide alignment of the joints during the gluing and setting operations and to allow faster clamping and less slipping under pressure. A tongue $\frac{1}{8}$ in. deep is just as valuable for this purpose as one $\frac{1}{4}$ in. deep.

The difficulties of making a perfect fit and of applying pressure are more pronounced with irregularly shaped joints and mortice-and-tenons and angle dovetails. Where waterproofing is not a factor, animal hot glues or caseins, which are easy to spread by hand, are gap filling and need little pressure, cannot be bettered. Mortice-and-tenon joints, such as those between square section rails and square section legs of chairs, are very highly stressed and the necessity for tight fitting is best appreciated when it is realised that, although there are five gluing surfaces, there are only two which can develop full gluing strength, all the others being "butt joints". The weaknesses of "butt joints" are explained in the next section.

Highly stressed mortice-and-tenons can be much improved by care in design of their proportions and by cross dowelling.

Machine marks, caused by feeding the stock through a planer or jointer too fast for the speed of the knives, are a cause of bad jointing and also of undulating veneered surfaces.

Another cause of unsatisfactory work is unequal thickness of

stock, due to neglect to compensate, by machine adjustment, for grinding, setting or wearing of the machine knives.

IMPROVING BUTT JOINTS

Butt joints are those in which the end grain of two pieces of wood are butted together or the end of one is butted to the side of the other. Mitred joints present so much end grain that they are considered generally as butt joints.

The nature of wood makes butt joints weak ones and their gluing is more difficult than that of side ones, whilst the stresses placed upon them are more severe. Tests made by the U.S. Forest Products Laboratory have shown that even with the most careful gluing, end joints cannot be obtained with more than 25 per cent. of the strength of parallel-grain joints.

In order to overcome the weakness of end joints, scarfing, fingering or serrating is carried out. The easiest operation is scarfing, which should be carried out at a slope not steeper than 1 in 10. To create a joint as strong as the solid timber, it is necessary in most species to make the slope 1 in 15. This is also the correct slope for joints in plywood sheets.

It is impossible to make strong end-to-side butt joints, not only because of the porous nature of the end joint, but also because of the uneven stresses. Under changing moisture conditions the end-grain half of the joint swells and shrinks considerably along both dimensions of the joint, whilst the piece to which it is glued moves in one direction only. Such joints are strengthened considerably when they can be banded on their faces by cross-veneers, such as occurs where they are used in the lattice cores of some flush doors. These are formed into stress-skin construction by the addition of the face plies bonded on under pressure. "Sizing" the end grain of a joint and allowing the "size" to dry before the main gluing operation creates a "sealing coat" and assists considerably in strengthening the joint by stopping undue glue absorption and consequent joint starvation.

LAYING HIGHLY FIGURED VENEERS

This is really the same problem as butt-jointing. Laying burrs, curls and figured butts entails the laying of end-grain porous veneers, and much trouble can be avoided by first "sizing" both

sides of the veneers with a warm solution of animal glue, mixed 1 part glue to 4 or 5 parts water.

The "sized" veneers should be dried and flattened in a press before laying. It is good practice with these highly figured and consequently wild or tangled-grained veneers to use a mild cross veneer between the facing and the core, whether the latter be solid, ply, laminated or of block construction.

Some manufacturers prefer to glue the face veneer to the cross veneer as a first and separate operation before gluing both to the core.

PREPARATION OF SURFACES FOR GLUING

Surfaces to be joined should be machined or hand finished accurately, so that close, even contact can be made over the whole of the gluing surfaces.

Grease stains must be removed before gluing, as must also any exudation of casein cement from joints which are to be surfaced by bonding of veneers with synthetic-resin adhesives.

Close-grained hardwoods, resin-bonded plywood if scraper finished—i.e. having a polished surface—as well as impregnated woods and vulcanised fibre should be sanded before gluing and all sander dust removed.

INCREASING GLUING AREA BY SURFACE TREATMENT

A good glue joint is practically invisible and, as previously stated, is as strong or stronger than most of the light and medium timbers, butt joints only excepted.

When it is desired to develop the full strength in the joints of some of the heavy and exceptionally strong and tough timbers, the joints should be toothed or rough sanded across the grain. Tests with weak glues and strong timbers have shown that glue joint strengths may be increased by as much as 50 per cent. by first roughening the surfaces to be jointed.

It will be obvious though that, as the cost of the roughening process fully offsets the saving on the glue, there is no benefit except where the strength of the timber is greater than that of a normal glue joint and it is desired to bring the strength of the joint up to that of the timber.

CHEMICAL TREATMENT TO IMPROVE JOINTS

Certain woods, such as maple, birch and red gum, are difficult to glue and are particularly prone to joint "starvation". Naturally

oily woods, such as teak, osage-orange and cedar, also give trouble in gluing. In such cases, the U.S. Forest Products Laboratory has obtained improved gluing results by chemical treatment of the surfaces, details of which, by their kind permission, are given in the appendix to this chapter.

A FACTORY METHOD FOR TESTING HARDNESS OF GLUE JOINTS

Woodworkers have found that glues are usually more abrasive than wood and that tools dull rather quickly in the machining of glued products. Some glues are harder than others and if the glue-line of a joint made with a very hard glue is allowed to pass its entire length several times over the same spot in a planer knife, a "nick" is very likely to develop that is expensive to remove. In many cases, therefore, it would pay a manufacturer in selecting a glue for his particular requirements to choose the glue which is the least abrasive of those having the qualities he desires.

The U.S. Forest Products Laboratory suggests the following test to determine the comparative hardness of joints made with different glues:

"A number of pieces of wood (preferably softwoods) are glued together face to face, each individual joint being produced with one of the glues to be tested. After the laminated block has been allowed to condition for a week or more, one edge is cleaned of excess glue and squared up. The block is then run repeatedly over a jointer in such a way that each glue-line passes over only one spot in the cutter. The depths of the respective nicks caused by the hard glue-lines are then a rough measure of the abrasive effect of the glues.

"It is rather difficult, however, to detect differences in the nicks by a mere visual inspection. A better means of comparison is afforded if a smoothly planed softwood board is run across the dull knives."

Appendix to Chapter 5

U.S. FOREST PRODUCTS LABORATORY TREATMENT ENTITLED: "CHEMICAL TREATMENT OF SURFACES IMPROVES GLUE JOINTS IN CERTAIN WOODS" *

In tests at the U.S. Forest Products Laboratory a solution of caustic soda proved effective in reducing the tendency to "starved" animal-glue joints in woods in which this type of defective joint is common, and caustic-soda or lime-water treatments strengthened casein-glue joints in woods that ordinarily are joined with this glue with some difficulty.

The caustic-soda treatment used in the tests consisted of a brush application to the surfaces to be joined of a solution of 10 parts by weight of caustic soda to 90 parts of water. After about 10 minutes the surfaces were wiped with a cloth to remove any excess solution or dissolved material and allowed to dry before being glued.

Tests of Animal-Glue Joints

The results of the tests on treated wood joined with animal glue under starved-joint conditions are indicated in Table 1 in such a way as to show whether the treated joints gave higher or lower tests results—with respect to strength in shear and percentage of wood failure—than joints glued without preliminary treatment under both good and starved-joint conditions.

The entire group of treated joints—13 species—showed 51 per cent. greater average strength in shear than the untreated joints of the same species glued under starved-joint conditions, and 97 per cent. more wood failure.

In the case of the caustic-treated black walnut listed in Table 1, although the strength values were less than those for untreated wood, the improvement in the starved-joint condition is indicated by the increase in the percentage of wood failure. With the black walnut the lower strength of the treated joints was apparently due to poorer quality wood.

* In the case of most of the native American woods the trouble and expense of treating joints with caustic soda is not justified, as joints as strong as the wood can be obtained in the majority of species through the use of proper gluing conditions. *U.S. Department of Agriculture Bulletin No.* 1500, "The Gluing of Wood" summarises the Forest Products Laboratory's information and recommendations on gluing.

TABLE 1. EFFECT OF CAUSTIC SODA ON ANIMAL-GLUE JOINTS
(Wood treated with caustic soda and glued under starved-joint conditions.)

Species of wood	Average strength, lbs. per sq. in.	Average wood failure, per cent.
Basswood ..	++ ·	+ .
Yellow birch ..	++	+
Black cherry ..	++	++
Red gum heart	++	+ .
Red gum sap ..	++	+
Sugar maple ..	++	++
Red oak	++	+
White oak	++	++
Osage-orange..	+	+.
Northern white pine..	++	—
Southern yellow pine	++	+
Yellow poplar	++	++
Black walnut ..	—	++

 + = More than value for untreated wood glued under starved-joint
       conditions.
++ = More than value for untreated wood glued under either starved-joint
       conditions or good gluing conditions.
 — = Less than value for untreated wood glued under either starved-joint or
       good gluing conditions.

TESTS OF CASEIN-GLUE JOINTS

The results of tests of caustic-treated casein-glue joints are presented in Table 2. This table is similar to Table 1 except that starved joints do not enter the comparison of treated and untreated joints.

Tests on caustic-treated casein-glue joints in osage-orange, made independently of the tests on which Table 2 is based, gave striking results. Practically no adhesion at all occurred when this species—a wood containing a large amount of extractives and one of the most difficult of all woods to join with casein glue—was glued untreated. The joints showed an average strength in shear of only 294 lbs. per sq. in. and no wood failure. When treated with caustic soda the average joint strength was over 3,000 lbs. per sq. in. and the wood failure 35 per cent.

Lime water, ammonia, benzol, hydrochloric acid and bleaching powder (chloride of lime) were other materials tested at the same time as the caustic soda. Hydrated lime (10 parts added to 90 parts of water) gave slightly better results than caustic soda when used as a surface treatment for hickory, red gum, and

4   49

black cherry joined with casein glue. Of the other chemicals named above, some gave encouraging results on one or two species, but the results in general were not sufficiently consistent to warrant discussion in this note.

TABLE 2. EFFECT OF CAUSTIC SODA ON CASEIN-GLUE JOINTS
(Wood treated with caustic soda and glued under normal conditions.)

Species of Wood	Average strength, lbs. per sq. in.	Average wood failure, per cent.
Basswood ..	+	+
Red gum heart	+	—
Red gum sap	+	+
Hickory	+	+
White oak	—	—
White pine	+	—*
Redwood	+	+

* Difference insignificant.

$+$ = More than value for untreated wood glued under same conditions.
$-$ = Less than value for untreated wood glued under same conditions.

Chapter 6

ANIMAL GLUES

THESE are the true glues which set by loss of heat supplemented by absorption of water into the wood. They are sometimes called the "hot glues", heat being necessary in their manufacture, preparation and during their working life.

The best grades possess strong adhesive properties and are very dependable; they do not stain and they have no deleterious effect on the skins of their operators. Their water resistance is generally low, but may be improved considerably by treatment. By kind permission of the U.S. Forest Products Laboratory, details of a water-resistant animal glue are given in the appendix to this chapter.

Wood jointed with animal glue may be painted, varnished, cellulosed, waxed or french polished satisfactorily. The animal glues are the most foolproof marketed, and though they cannot give the best results when wrongly prepared and used, it is surprising what strong joints they do produce even in the most adverse circumstances.

For several centuries they have been the standard glues of the cabinet-maker, joiner and carpenter. Some would say for many centuries; but it is extremely doubtful if glue was used to any large extent in European woodwork from the fall of Rome up to the beginning of the sixteenth century. Careful examination of pieces of furniture genuinely made before that date shows that the majority of tables, benches and other simple pieces usually had single plank tops and other flat surfaces, and that where joints were needed they were tenoned and draw-pegged dry or butt-jointed and strengthened with iron strapwork. In fact, the designs of furniture up to the sixteenth century and sometimes later speak eloquently of the limitations that were imposed by the lack of an adhesive sufficiently strong to use constructionally.

English furniture of the sixteenth and seventeenth centuries was still very often made dry, and it was probably the introduction of inlay into our furniture, in the sixteenth, and veneering

in the second half of the seventeenth century, that aroused the need for and developed the use of a reliable wood adhesive. In some parts of the Continent it was in common use at least a century earlier than in England. How greatly it has influenced design and construction may be gauged by comparison of the thirteenth-century chest illustrated in Plate 1, the early seventeenth-century chest in Plate 2 and the late eighteenth century chair shown in Plate 3, all of which are reproduced by courtesy of the Victoria and Albert Museum. The typical thirteenth-century chest in Plate 1, by reason of the lack of adhesives, was designed with the front and back each composed of a single-board panel flanked by broad wedge-shaped, single-board stiles, the two front ones of which are curved below on the inner sides to form an arch. The lid is a single board. In Plate 2 glue has arrived and has made possible the holly and bog-oak inlay of the panels, but the mortise-and-tenon joints are still held by drawpegs. In Plate 3, glue has become the reliable jointing medium, stronger than the wood itself, and has made possible the delicate design, the use of small sections of wood and the absence of stretcher rails.

Apart from width jointing and veneering, joints which in furniture and joinery are not and never have been fully stressed, glue was used only as a supplement and to give rigidity to and prevent the "working" of such conventional woodwork joints as mortice-and-tenons, dowel-and-sockets, dovetails, etc. Where the joints have been well stressed, as in chairs, they have usually been taken apart and reglued periodically. It is doubtful if there are any Stuart or Queen Anne and probably very few early Georgian or even Chippendale, Hepplewhite and Sheraton chairs extant that have come down to us with their original glue joints intact.

Many of the early Victorian chairs, though, show no evidence of having been reglued, and it does seem, therefore, that animal-glue joints, even when fully stressed, have a life of approximately a hundred years.

Animal glues are divided into three main classes: hide, sinew and bone glues. Hide until recent years was the strongest, sinew the medium and bone the lowest strength, but improvements in the manufacture of bone glues have brought the strength of the best varieties up to the equal of hide. There are, however, variations in the strength of glue from cattle, goats, sheep, deer,

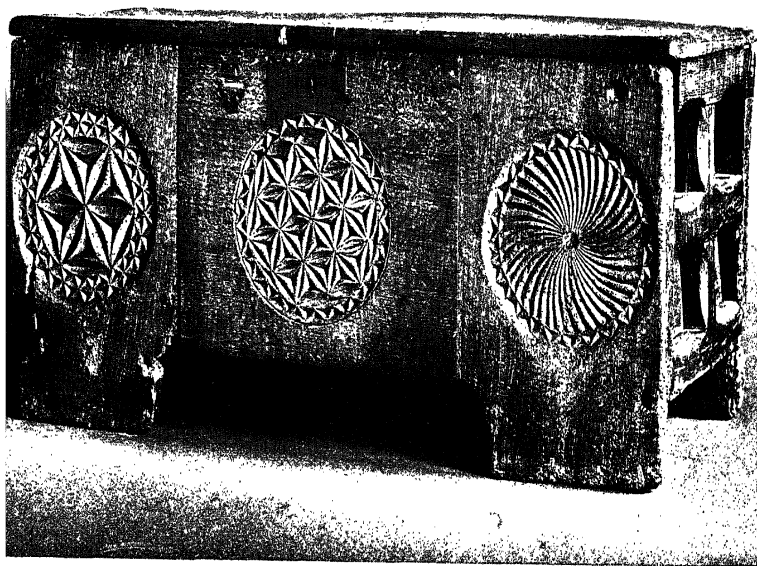PLATE 1. THIRTEENTH-CENTURY CHEST OF DRY CONSTRUCTION
Photograph by courtesy of the Victoria and Albert Museum
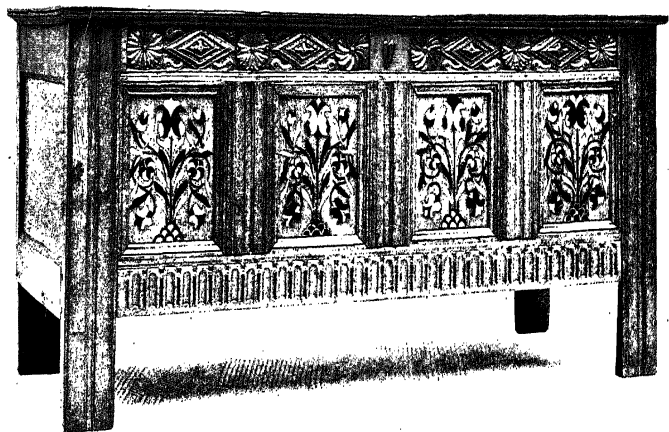

PLATE 2. EARLY SEVENTEENTH-CENTURY CHEST. THE TENONS ARE STILL HELD BY DRAW PEGS BUT THE INLAY OF THE PANELS IS GLUED
Photograph by courtesy of the Victoria and Albert Museum

PLATE 3. LATE EIGHTEENTH-CENTURY MAHOGANY CHAIR OF GLUED CONSTRUCTION
Photograph by courtesy of the Victoria and Albert Museum

horses, pigs, rabbits and other animals. Cattle glues are the strongest and the others descend roughly in the order given.

All three classes are sold in cakes, flakes, granulated pearl and other forms, which, though having no bearing on the quality, affect the speed with which they can be dissolved. The nearer a glue is to a powder, the more easily it absorbs water and goes into solution. The cakes, therefore, take the longest time, but they may be speeded up if required by breaking before soaking. Some cake glue is known as Scotch and other as French or medal glue, but both are made in England in imitation of the forms of glue which were formerly made in Scotland and France respectively. The original manufacturers of glue in Scotland inserted string in their glue cakes in order to hang them up to dry in the open air; to reduce the number of strings, they made the cakes thicker than is now normal. The Scotch glue now made is usually dried on nets, but strings are sometimes still inserted so that the users can have the pleasure of taking them out again when the glue is melted! The French or medal glue obtained its name from the *medaille d'or* which was awarded for glue manufactured at certain exhibitions in France.

Most of the high-grade glues are light in colour and semi-transparent, whilst the inferior grades, used mostly for veneering, are in their natural form dark and opaque. Colour and transparency, however, cannot be taken as a criterion of quality.

The safest course is to buy from a reputable manufacturer, for it is not unknown for low-grade glues to be bleached, while the transparency of the high grades is sometimes destroyed deliberately by the addition of zinc white, chalk, etc., added in order to give an invisible glue-line in joints. In small quantities, these additions apparently do not affect the strength of the glue adversely, though certainly they do not enhance it.

The actual manufacture of glue from hide or from sinew and bones is lengthy and involves complex processes. It need not concern us greatly, but the following brief description may be of interest.

Glue stock of the hide type is generally made as follows. First the skins are soaked in lime water or weak soda solution to remove hair and other impurities; then they are washed in dilute acid. After various operations, the "stock" is placed in water and heated to a temperature of 140° F. (60° C.) and the collagen, a complex and insoluble protein body present in the

raw materials, is thus hydrolised into the soluble, jelly-forming substances constituting glue.

The hydrolysis continues beyond the formation of these products and gives rise to compounds which have no jelly-forming propensity and are of little value as adhesives. For this reason the glue is drawn off and clarified and a fresh quantity of water is added to the stock and a second cooking made. This operation is repeated several times, each cooking being at a slightly higher temperature, but the temperature of the last batch must never exceed 212° F. (100° C.) or the glue will be degraded.

Bones and sinews commence their processing into glue by sorting and grading according to glue value. They are then coarsely ground and degreased by the benzine process, after which they pass over magnets to remove iron, which, if left in, blackens the glue. The ground bones are then deglued in special extractors after being polished in rotating drums which are per-forated to allow the dust and any remaining hairs to fall through.

The solution of hide or bone glue from the boiling kettles is thickened by evaporating off the water until the glue in solution is sufficiently concentrated to form a firm jelly when cool. When it reaches this stage, it is either cooled in shallow pans or by refrigeration as it passes along belts in a continuous sheet. While travelling along the belt it is cut into sections and placed on wire screens, which are transferred to a drying chamber where the glue hardens into cakes. These are now ready for selling as cake glue or they may be cut into flakes or ground into pearl, crystal or powder, or converted by the manufacturer into jelly glue before sale.

The sequence of operations from the purchase of the glue is what is of most concern here, and the first condition to which attention must be given is the storage. Hard glues are delivered in sacks and they must be kept in a dry, cool place. Damp or heat may lead to bacteriological infection and will alter the capacity of the glue to absorb water. The jelly glues are sold in cans, but they too should be kept in a dry, cool place. They cost more than the hard glues, but this is natural because the first three of the seven operations enumerated below have been carried out already by the manufacturer and the user has been saved these labours, with their possibilities of error. Moreover, some of these jelly glues have high moisture-resistant properties, which are absent from ordinary mixes.

The operations for glue purchased hard are as follows:

(1) Absorption
(2) Soaking
(3) Melting
(4) Keeping in solution
(5) Application
(6) Setting
(7) Cleaning off

Scrupulous cleanliness should be bracketed to these seven operations and kept to the forefront all the time, for without it gluing cannot be efficient and must be unpleasant. Strict cleanliness must be observed both in the glue-making kitchen and wherever the glue is used; if this is done, there will be very little odour. Burnt glue and decomposed glue both smell foul, but there is no need for either in an efficiently run factory. Mixers, pots, brushes, troughs, spreaders, presses, clamps and all other gluing apparatus, as well as floors in their vicinity, should be scraped daily and cleaned with disinfectant.

Old glue soon becomes obnoxious and forms a breeding-ground for the putrefying bacteria, which will contaminate fresh batches. Glue should be prepared fresh daily, only enough being mixed for a day's run. In no part of a woodworking plant does cleanliness pay a higher dividend in efficiency than in the gluing section.

A scheme that was operated before the war by a well-known furniture company in this country was to divide the whole factory into comparatively small sections, which competed over a period in a "Health and Cleanliness" competition. For this, prizes were offered by the management to all the workers in the winning section. This section also held a silver shield, which was engraved with their "win" and was not taken away until it was won by another department. Three successive wins by any one section gained it a permanent miniature silver shield. The scheme was a great success and it was not unusual for the prizes to be won and the shield displayed by either the glue kitchen, the glue jointing, the veneering or the glue finishing section, which just shows what can be done with the generally accepted "dirty" sections of a factory.

The Standard Specifications and Methods for the Determination of moisture content, chlorides, reaction, joint strength in

shear, and tests for the valuation of various properties are given in the appropriate British Standards Specifications, which can be obtained from The British Standards Institute.

The dry joint strength in shear—i.e. load required to break the specified glue joint when tested by the method described in the specification—must not be less than 1,000 lbs. per sq. in. This figure is readily obtainable with joints correctly made from any good, commercial-quality animal glue and dry timber of the variety nominated.

Absorption

No hard-and-fast rule can be laid down as to the proportion of water that should be added to glue, as this varies according to the density of the wood and the type of work that is being undertaken. When experience and test have shown the best proportions for a given purpose, they should be maintained by weighing the dry glue and weighing or measuring the water in all subsequent batches. The materials should be placed in a clean vessel and stirred to ensure uniform absorption of water by the dry glue.

Soaking

It is essential that the glue be covered entirely by the water. The soaking will take two or three hours, when the glue will be found soft and ready for melting. Leaving the glue to soak longer than three hours does no harm—provided the glue, the water and the vessel are clean. Some woodworkers find it more convenient to leave a batch to soak overnight.

A good glue will absorb about $2\frac{1}{4}$ times and never more than 3 times its own weight of water.

Melting

This process (sometimes termed cooking), which is the most important, should be carried out in a double jacketed water container or mixer, heated by steam, gas or electricity. An open flame should not be used, because careful control of temperature is important and it should never exceed 150° F. (65° C.). High temperatures and heating for an unnecessarily long period both reduce the strength of the glue and aid its decomposition, thus causing waste of material and unsatisfactory results. Most of

the damage done to glue occurs in this melting process and it is usually as a result of excessive heat, which breaks down the innumerable small animal fibres on whose strength depends the adhesiveness of the glue. Heat is used to break down the toughness of a joint of meat, and if it is applied too intensely or too long to animal glue, it will break down the toughness in a similar manner.

To assist preservation and give a clean smell, some users add phenol (2 per cent. by weight) to the jelly before melting.

During melting, the glue must be stirred either by mechanical fan blades or by hand methods. Where the output justifies it, the mechanically stirred container is the best, as, apart from the greater perfection of the mixing, the vessel is fitted with a lid which can be kept closed all the time and helps to prevent skin or scum, which otherwise forms on the surface of the glue. The rotation of the blades should be slow, or else the glue will froth.

Some manufacturers of animal glue in powder form recommend adding the glue to the water, pouring in slowly to prevent frothing. Only clean water should be used and precautions to ensure freedom from rust should be taken.

Keeping in Solution

When melted, the glue must never be boiled, but it must be kept hot in the pots or troughs at a temperature not exceeding 140° F. (60° C.). The ideal temperature is 120° F. (49° C.), at which heat the glue has a working life of a day. If it becomes too viscous, as a result of evaporation, water should be added and stirred in thoroughly.

All glue-pots should be of the double-jacket type, equipped with a water gauge, thermostatic control and having a red alcohol line thermometer or a needle dial registering the heat of the glue.

Overheating is one of the most serious causes of glue loss and weakness. It is not unusual to find glue being kept in solution at 175° F. (79° C.). At this temperature it loses strength at the rate of $2\frac{1}{2}$ per cent. per hour—i.e. 20 per cent. in the average working day. Evaporation is another heavy loss, not only through loss of the "body" of the glue mixture, but also due to the consequent skin that forms. Covers for the apparatus are the best means of saving this loss.

If it is necessary to remove a glue-pot from its hot jacket—i.e. source of heat—the effective working life of the glue is very short and the actual gluing operation must be carried out expeditiously. Only too often bad joints result from laziness, due to the use of chilled and over thickened glue. In this connection, the U.S. Forest Products Laboratory states:

When the temperature of the room and the wood is	The assembly period in minutes may be
70° F.[1]	$\frac{1}{2}$ to 1
80° F.[2]	3 to 5
90° F.[3]	10 to 18

In this country, workshop temperatures seldom exceed the safe minimum of 70° F. (21° C.) and unfortunately they are very often as low as 50° F. (10° C.). It is unfair to the glue when this latter condition exists, particularly if the low temperature is due to draughts which cause skin on the glue.

If hot glue must be used in such circumstances, chilling can be counteracted considerably by heating the wood that is to be jointed; about 95° F. (35° C.) is the ideal temperature and this can be obtained easily on a hot-plate. Unless some such precautions are taken, bad work will result.

Application and Pressure

Animal glues are easy to apply by hand brush and hot jacketed pot, or mechanically by hot jacketed wheel, roller, or rise-and-fall trough.

The first things to remember are that hot rooms with hot glue (which are ideal) allow long assembly time, because the glue "gels" slowly. The best results are obtained with slight pressure. Quite irrespective of temperature, it is a cardinal rule that thin glue needs only slight pressure, in order to avoid starved joints. The consistency is increased either by increasing the assembly time or by decreasing the room temperature. Cold rooms tend to thicken and chill the glue and make rapid assembly essential. Thick glue, whether chilled or not, needs high pressure.

These points lead to the fact that the making of a good glue joint is dependent primarily on the correct correlation of pressure

[1] 21° C.   27° C.   32° C.

and glue consistency and the latter, in its turn, is dependent largely on the temperature and moisture evaporation of the glue, though the temperature of the room and the wood naturally affect it.

For the first few minutes after application, the rate of cooling, which should be slow, is more important than the evaporation of the glue: hence the emphasis on the importance of not using animal hot glues in a cold workshop or on cold wood. The best grades of animal glues chill and thicken at a higher temperature than do the lower grades. Unlike many other adhesives, animal glues should not be used thick (either through insufficient dilution or through chilling) if the strongest joints are to be obtained. Although this type of glue should be used only whilst it flows freely, it should not be used meanly or made to such a thin consistency that it percolates too far into the wood and starves the joint. A starved joint cannot be rectified, and animal glue does not stain wood if it squeezes out, whilst the surplus can be removed easily when it "gels". Very little pressure is needed with rightly made and used animal glues. The glue blocks used largely in cabinet making, joinery and carpentry angle-work are fixed by suction created by firmly pressing and rubbing the blocks backwards and forwards a few times, until the suction of the glue causes increasing resistance to the movement. Not only short blocks but satisfactory edge joints up to six feet long are still made in small workshops by this method, which equals a pressure of 25 to 50 lbs. per sq. in.

In veneering and plywood manufacturing, owing to the size of the surface to be veneered or the time taken in emptying and loading the press, the glue chills before pressure can be applied. In such cases, fresh heat must be applied. Until a few years ago, this was done by means of a hot iron, or with heated metal cauls used in conjunction with a hand-operated cold press. Now it is more often done in a hot-and-cold press. This consists of an electrically or hydraulically operated press with a number of horizontal hollow metal platens honeycombed with a grillage of pipes. The assemblies are placed in the daylights between the platens, the heat turned on, the platens closed down and the desired pressure applied. Next, the hot water is forced out of the pipes and cold water run in to "gel" and set the glue. The whole operation takes only a few minutes and several batches can go through the press in one hour. The press pressure normally

should be 150 lbs. to 200 lbs. per sq. in. and the temperature between 140° F. (60° C.) and 150° F. (65° C.), applied for not more than 6–7 minutes. If, for some reason, pressure must be applied after the glue has chilled or thickened, a pressure of 400 lbs. per sq. in. may be needed. Increase in temperature or in the hot time will draw the glue through the veneer and ruin the finished article. To prevent glue percolating through porous veneers or showing through very light or thin ones, it is common practice to add small proportions of chalk substances to the glue. The manufacturer's recommendations should be followed carefully as regards the maximum percentages of these preparations which should be used. Rubber bag presses, operated on the same principles, and vacuum presses are used for curved work. These are more fully described in Chapter 15.

Cleaning off

When it is necessary to leave surplus animal glue until it has hardened, it can be removed quite easily by planer or scraper, either hand or power operated, and it does not wear the knives or cutters badly, as do some other adhesives. It does, however, soon clog glass or garnet paper.

Machining operations should not be undertaken until 8 to 12 hours have elapsed from the time of the application of the glue.

Addendum to Chapter 6

U.S. FOREST PRODUCTS LABORATORY'S REPORT:
"WATER-RESISTANT ANIMAL GLUE,"
by F. L. BROWNE, Senior Chemist

The Forest Products Laboratory had found that it is practicable to give ordinary animal glue a fairly high degree of water-resistance by incorporating certain chemicals with it just before application. A detailed description of the experiments was published in *Industrial and Engineering Chemistry*, Vol. 19, p. 215, February, 1927. The formula herein described has given very excellent results on the laboratory scale and is believed suitable for certain types of manufacturing operations. In a typical test with three-ply panels of $\frac{1}{16}$-in. birch veneer, average shearing

strengths of 475 lbs. per sq. in. when dry and 165 lbs. per sq. in. after soaking in water for 2 days were obtained. This is within the range of values shown by good water-resistant casein glues.

FORMULA

Animal glue .	100	parts by weight
Water * .. .	225	,, ,,
Oxalic acid.. .	5·5	,, ,,
Paraformaldehyde	10	,, ,,

* The proportion of water will depend upon the grade of glue employed and the viscosity of solution desired. In general, the proportion will be the same as would be employed when using the glue in question without addition of chemicals.

The glue is soaked in the cold water until the granules or flakes have been softened. It is then melted at about 140° F.,[1] after which the temperature is allowed to fall to between 105° [2] and 115° F.[3] The oxalic acid, in small crystals, and the paraformaldehyde (a fine, white powder) are then mixed together and added to the glue. The mixture is stirred until all of the oxalic acid has gone into solution, after which it is ready for use. Another good procedure is to soak and melt the glue in 200 parts of water, saving the other 25 parts to moisten the paraformaldehyde and oxalic acid before adding them to the glue solution. Any tendency for the paraformaldehyde to form dry lumps when incorporated in the glue is thereby eliminated.

PRECAUTIONS IN USING THE GLUE

At a given temperature the addition of the oxalic acid and paraformaldehyde lowers the viscosity of the glue slightly. But the new glue is used at lower temperatures than are customarily employed for animal glue, so that the difference in viscosity brought about by the added ingredients is compensated for by the effect of the lower temperatures at which it is used. It will be understood, of course, that the water content may be altered at will to give a glue of any desired viscosity or to suit the requirements of different grades of animal glue.

Care must be taken to keep the glue within the proper range

[1] 60° C.   [2] 41° C.   [3] 46° C.

of temperature. At a temperature between 105°[2] and 115° F.[3] and when using the proper type of paraformaldehyde, the glue will remain in a fluid condition for 6 to 8 hours from the time of incorporating the paraformaldehyde and oxalic acid, after which it will set to a tough, firm jelly which cannot be melted again. *It is important to avoid heating the glue mixture above* 115°[3] if a long working life is required. At 120° F.[4] the working life is 5 to 6 hours and at 140° F.[1] it is only 2½ to 3 hours. The working life does not seem to differ materially with animal glues of widely varying grade.

The low temperatures advised can be employed without danger of decomposition of the glue through bacterial action because paraformaldehyde is an excellent antiseptic. Because of this lower temperature and the lower gel-point caused by the added chemicals, a slightly longer assembly period may be allowed in the gluing operations than would ordinarily be employed with the grade of animal glue used.

The paraformaldehyde does not dissolve in the glue at once, but most of it remains suspended as a finely divided solid during the working life of the glue. A certain amount of agitation is therefore necessary to keep it evenly distributed throughout the mixture, preventing its settling to the bottom of the container. The paraformaldehyde used should be a fine enough powder to pass completely through a 50-mesh sieve, in which case the amount of agitation provided by the mechanical glue spreader is sufficient to keep the paraformaldehyde stirred up. The glue should be stirred thoroughly in the mixer just before taking it to the spreader or to bench glue-pots.

It is important to use up a batch of glue and *clean the spreading machinery and glue-pot* before the glue sets to a jelly because the tough, insoluble jelly is not easy to remove.

Type of Paraformaldehyde to use

Commercial paraformaldehyde varies materially in certain of its properties, notably in its chemical reactivity. When used in this formula, some types of paraformaldehyde cause the glue to set to an unworkable jelly in a much shorter period of time than the working life as stated above. For example, glues were made up in accordance with the formula using paraformaldehyde from

[1] 60° C.   [2] 41° C.   [3] 46° C.   [4] 49° C.

five different factories and the range in working life at 115° F.[1] was found to be as follows:

Source of paraformaldehyde. Factory number	Working life of glue Hours
1	6·5
2	5
3	3
4	2·75
5	2·5

By heating a fast-reacting paraformaldehyde in a closed container at 212° F.[2] for several days it can be made slow-reacting. The chemical reactivity, however, is subject to control during the manufacture of the paraformaldehyde. . . .

INFLUENCE OF GRADE OF GLUE

When glues of different grade are employed in this formula it is necessary to vary the amount of water used in order to maintain the same viscosity of the glue solution, just as would be the case in employing the glues without addition of chemicals. Aside from this, different animal glues give approximately the same results. Such small differences in working life, joint strength, and water-resistance as are observed with individual animal glues seem to be more or less independent of the glue grade measured in terms of viscosity and jelly strength, as the following results show:

Grade of glue *		Working life, hours	Plywood tests, lbs. per sq. in.		Joint test	
Viscosity, Millipoises	Jelly strength, Grams		Dry	Wet	Lbs. per sq. in.	Wood failure, per cent.
118	372	7	449	139	3,560	31
95	299	7½	463	163	2,600	36
76	240	6¼	452	155	3,385	38
65	190	7	—	—	—	—
55	131	7	449	113	3,720	39

* Glue grade measurements were made by the methods of the National Association of Glue Manufacturers, *Indus. Eng. Chem.*, 16, 310, 1924.

WATER-RESISTANCE DEVELOPS SLOWLY

Test panels for determining the degree of water-resistance of this formula should be seasoned after gluing for at least 10

[1] 46° C. [2] 100° C.

days before subjecting them to the soaking test, because the full degree of water-resistance is developed slowly. A number of panels were made up with a single batch of glue and seasoned for varying lengths of time before testing, with the following results:

Days seasoning	Plywood test, wet, lbs. per sq. in.
2	20
3	65
5	95
7	115
9	140
10	150
12	145
17	155

It should also be noted that the water-resistance of glues made by this formula is comparable with that of casein glues when the soaking test is carried out in water at ordinary room temperatures or less, but in water at higher temperatures the values obtained in the test on the paraformaldehyde animal glue decrease with increasing temperatures. Thus, a series of tests gave the following data:

	Lbs. per sq. in.
Specimens tested dry	409

Specimens tested wet after
2 days' soaking in water at:

	Lbs. per sq. in.
59° F.[1]	188
77° F.[2]	174
95° F.[3]	138
113° F.[4]	94
140° F.[5]	0

OTHER CHEMICALS THAT MAY BE USED

Both oxalic acid and paraformaldehyde are poisonous materials. Proper precautions should be taken to see that they are not ingested by men using them. The oxalic acid can be replaced by an equal weight of the non-poisonous mucic acid. Any acid will serve to extend the working life to a satisfactory period, but many of them affect either the dry strength or the water resistance adversely. There are a number of other substances that can be used in place of paraformaldehyde, but they all give off formaldehyde in the glue and are therefore just as objectionable from the point of view of poisonousness as paraformaldehyde. Further details regarding them will be found in the reference previously cited.

[1] 15° C.   [2] 25° C.   [3] 35° C.   [4] 45° C.   60° C.

There is no detectable odour of formaldehyde in panels glued with this formula.

This glue may prove of value where high water-resistance is desirable and where other glues are not suitable for one reason or another. It is not alkaline and will not stain thin veneers. There is no reason to suppose that it will dull wood-working tools to any greater extent than ordinary animal glue.

Persons contemplating trying out this formula should communicate with the Forest Products Laboratory, Madison, Wis., U.S.A., if they wish its suggestions in adapting the process to their special requirements.

CASEIN CEMENTS AND VEGETABLE PROTEINS

M UCH is being written about "ply plastics" and the "marriage of wood and plastics." Actually what the writers appear to mean is the use of the new synthetic-resin waterproof glues for jointing wood.

The generally accepted definition of a plastic is that it is a material which, at some time in its history, is capable of flow and which, on the application of the necessary pressure and/or heat, can be made to take up a desired shape. Assuming this to be correct, the old-established caseins are just as much plastics as the new synthetic resins.

The use of casein adhesives is reported to go back to the time of the Pharaohs; whether they remained in continuous use from then onwards is not known, though certainly they were in service again at the time of the Renaissance. They seem to have continued in Europe ever since, but only to have been manufactured on a commercial scale towards the end of the last century. The first patent for a waterproof casein cement was granted to a Mr. Christian Luther of Reval in 1892.

The use in England and the U.S.A. was very limited until the First World War, when the need for a highly water-resistant adhesive for aircraft construction brought casein to the fore.

Although, in the latest aircraft, largely superseded by the waterproof synthetic resins, the water resistance of casein cements, which varies according to the mix, can be made sufficient for many constructional purposes.

The casein cements are easy to mix and apply and are valuable and economical adhesives for the general and constructional wood-working and plywood industries.

Like all other adhesives they have their limitations, and when used improperly or for unsuitable purposes they will not give satisfaction.

The caseins have the great advantage of being "cold" adhesives:

no heat is required either in their preparation or use, though heat may be used to speed up their set, which is partially a chemical reaction, accelerated by increase of temperature. In these respects, caseins are exactly the opposite of the animal glues.

Manufacture

Casein is the chief protein constituent of milk and the word is derived from the German *Käse*. When milk goes sour, it separates into curds and whey. The curd, when washed and dried, is casein. Milk may be soured naturally or the casein precipitated by the addition of rennet or mineral acids, such as hydrochloric or sulphuric.

After the precipitation of the casein, the sequence of operations in the manufacture of the adhesive is as follows. The curd is washed to remove the acid and any other impurities and is pressed in a cloth to remove as much as possible of the water before the final drying out and grading into powder. It is then ready for mixing with the other ingredients necessary to form the type of adhesive required. The type and proportion of these other ingredients decide the water-resistance and working life of the cement.

The principal ingredients of casein cements are casein, hydrated lime, sodium hydroxide (i.e. caustic soda) and water. The hydrated lime provides the water resistance but shortens the working life, while the sodium hydroxide extends the working life but lowers the water resistance.

An adhesive may be made with casein, hydrated lime and water only, or with casein, sodium hydroxide and water only. The first mix, if properly proportioned, will have extremely high water resistance but very short working life, whilst the second will have good dry strength, low water resistance and a long working life. Carefully adjusted mixtures of these three ingredients and water give adhesives to suit most woodworking purposes, but the manufacture is not as simple as it sounds and it is best to buy the ready-mixed powder from a specialist.

Sodium hydroxide is hygroscopic and its inclusion in a dry mix may lead to decomposition of the powders while in store. To overcome this danger, manufacturers usually replace the sodium hydroxide by chemically equivalent quantities of calcium hydroxide and some chemical which, when dissolved in water, reacts with the calcium hydroxide to form sodium hydroxide.

Any sodium salt of an acid whose calcium salt is relatively insoluble may be used, provided it is neither hygroscopic nor reactive with the lime or casein in the dry mix. Sodium salts commonly used for this purpose are sodium oxalate, sodium tartate, sodium citrate, sodium salicylate, sodium phosphate, sodium sulphite, sodium fluoride, sodium arsenate, sodium arsenite or sodium stannate.

Casein cements are usually purchased ready mixed in powder form, requiring the addition of water only. They may be purchased in mixtures suitably blended to meet different requirements such as high water-resistance, long working life, ease in spreading, short setting time and low tendency to stain. Unfortunately no one mixture contains all these advantages and it is necessary to sacrifice one or more in order to gain another. Many of the formulæ used are secret or protected by patents.

The U.S. Forest Products Laboratory has carried out research into the use of copper salts for increasing the water resistance of casein cements without shortening their working life, and in their booklet on *Caseins* are given full details of the preparation, formula and method of mixing of a highly water-resistant casein/ sodium silicate/hydrated lime/copper salts adhesive that has considerable advantages but must be mixed at the place where it is to be used. By kind permission of the Laboratory, details of this mix, No. 11, and also of a simple casein/sodium hydroxide formula, No. 20, are given in the appendix to this chapter.

Testing

Casein of the highest grade is not essential, but to be suitable for adhesive purposes it must have a low fat and acid content, be sweet smelling, free from burnt or discoloured particles, not contaminated by moths, larvæ, maggots, etc. It should be ground to a powder fine enough to pass a 20-mesh sieve.

The specification and methods of determining dry strength and water resistance are given in the appropriate British Standards Specifications, which can be obtained from the British Standards Institute.

Storage and Mixing

Ready-mixed casein cement powders are delivered in airtight tins or drums, which should be kept sealed when not in actual use. They should be stored in a cool, dry place.

All casein powders tend to deteriorate on prolonged storage and they should never be kept for more than 12 months.

The heavier or finer of the different ingredients in a ready-mixed casein cement tend to settle at the bottom of the container, which should always be stirred right from the bottom if it has been left standing for any length of time. If this simple precaution is neglected, there is danger of variation in strength, water resistance and setting times of different mixes drawn from a single container.

Preparation for use

This is simple in the case of the ready-mixes. Place the cold water (in cold weather the water should be tepid) in the mixing container and add the powder in the proportion directed by the manufacturer. The water should never be added to the powder, otherwise it will "ball up" and become lumpy. The powder must be stirred in at once, but slowly, vigorously and thoroughly, either by means of a mechanical agitator or with a wire whisk. The stirring must be continued until the mix is free from lumps and of about the consistency of *Nestlé's* milk. Too rapid mechanical agitating or hand stirring will lead to frothing and subsequent joint weakness. A motor-driven cake or dough mixer or a baker's wire whisk is suitable for the mixing operation. An efficient mixer can be made by adapting a portable electric screw-driver or drill of slow speed, which only needs a length of rod fitted with a blade inserted in the chuck to form a paddle and it can be used in an ordinary galvanised bucket.

When in solution, the mixture is left for 15 or 20 minutes, then stirred for approximately 1 minute, a little water being added if the mix is too thick for spreading; it is then ready for use.

Casein cements are highly alkaline and corrode certain metals. For this reason the mixing vessels, whisks, or agitator blades, glue-pots, guns and other apparatus must not be of brass, copper or aluminium. Galvanised or enamelled iron, earthenware or wood are all satisfactory, but must be cleaned thoroughly before any residue of the mix has time to set. The cleaning should be with cold or tepid water. It must never be forgotten that, unlike animal glues, the set of caseins is not only irreversible but is speeded up by heat, and it will create unnecessary difficulties if any attempt is made to clean apparatus with hot water.

Working life

The length of working life of a casein cement is dependent primarily on:

(1) The amount of lime it contains (the more lime, the shorter is the working life and the higher the moisture resistance).

(2) The amount of sodium hydroxide it contains (the more sodium hydroxide, the longer the working life and the lower the moisture resistance).

(3) The consistency of the cement mix (thin mixes work longer than thick ones).

(4) The temperature of the room and the water used in the mix (hot weather or heated rooms speed the "set", which, as already stated, is partially dependent on a chemical reaction).

It is obvious, therefore, that where high water resistance is required, some sacrifice of working life must be made, but it can be offset, to a limited extent, by increasing the amount of water used in mixing and by keeping down the temperature of the gluing room. Care must be taken not to increase the water beyond the quantity allowed in the formula, otherwise the joints will be weakened.

When short working life is no drawback, everything is easy. A highly water-resistant mix has a life of 4 to 5 hours, and a medium a life of 6 to 8 hours. If the working day is 8 hours or more, it is advisable to have two mixes. Actually, it is always easier and more economical to gauge the day's requirements in two halves, as residue from one day should never be carried forward and added to the following day's mix.

Application

Caseins may be spread on a roller spreader or by means of a spray gun, glue can, fibre brush or wooden spatula.

Hair or bristle brushes must not be used. Rollers, guns, troughs, etc., must be cleaned thoroughly, immediately after use and brushes left to soak.

Assembly Time

It is impossible to lay down hard-and-fast rules as to the consistency of the mix or the rate of its set. Both must vary according to the purpose, but the cement when spread on the

wood does not thicken in a cold room nearly as rapidly as does animal glue. Usually 15 to 30 minutes elapse after spreading and before pressure is applied.

The best results will be obtained if the mixture has become tacky before pressure is applied, but in no circumstances must pressure be delayed until the cement has begun to go rubbery, otherwise a poor joint will result. The assembly time will vary according to:

(1) moisture content of the wood,
(2) consistency of the glue,
(3) quantity applied, and
(4) room temperature.

The drier the wood, the more viscous the cement, the thinner its layer and the higher the room temperature, the shorter will be the permissible assembly time.

Pressure

Pressure must be sufficient to ensure complete contact between the cement film and the surfaces to be joined, but high pressure is not necessary. From 100 to 200 lbs. per sq. in. is sufficient.

A thick, viscous mix will require more pressure than a thin one. The pressure should be maintained for at least 3 hours and may be required for as long as 12, varying according to the conditions set out in the preceding paragraph.

Kiln-dried wood at 90° F. (32° C.) will need 3 to 6 hours.
Air-dried wood at 60° F. (16° C.) will need 8 to 12 hours.

Moisture content of wood

No close control of moisture content is necessary. It may be anything from 3 per cent. to 20 per cent. A moisture content of 10 per cent. to 15 per cent. is suitable for most constructional purposes.

Working temperature

This also needs no close control when using casein cements. It may be anything from just above freezing to summer heat.

AMERICAN PRACTICE

The Americans call casein a "self-bonding" adhesive, and certainly its faculty of bonding under slight pressure, together with the lack of necessity for close moisture control and the

wide range of temperatures over which it may be used, make it the building joinery trade's "maid of all work" and the ideal adhesive for constructional work on site and where large assemblies have to be carried out, sometimes in the open air.

It can be used not only for planed or sanded surfaces, but also for sawn. Greater pressure than the normal should be used for sawn surfaces in order to ensure that good contact is made.

In the U.S.A. it is the most popular adhesive for prefabrication and site building and constructional engineering work in all positions not exposed to mould-producing conditions.

From the U.S.A. has recently come news of a new patent technique for using casein cements, based on the separate application method which, as applied to synthetic resin adhesives, is more fully described in Chaper 10.

In this method, the diluted hardener is applied to one surface to be glued and may be spread by any suitable means, such as a brush, felt rolls or spray gun. The minimum quantity to give complete coverage is advisable. It is stated that one quart of the diluted hardener will cover approximately 100 sq. ft. of glue-line. It will remain effective on the surface for any period up to several months and may be applied at any convenient stage prior to the gluing operation. A special liquid casein cement is applied to the opposite surface in the customary manner and the adjacent units are placed in position for pressing. They must not be allowed to touch each other until contact and pressure can be developed simultaneously. Full pressure should be obtained within 15 seconds of contact. For this reason, it is recommended that pneumatic clamping tables should be used (as described in Chapter 15). The pressing time depends upon the type of joints, but, ordinarily, 30 seconds to 5 minutes is all that is needed where joints will not be under strain upon release of pressure.

It is claimed that the immediate bond developed is ample to permit reasonable handling and processing, but will not withstand rough pressure or heavy strain until after 30 minutes or more.

Tests made at the U.S. Forests Products Laboratory give the following approximate comparative strengths of different methods of laminating beams:

	Units of Maximum Load
Nailed only ..	100
Nailed and glued	228–282
Glued and clamped	232–358

Water resistance

Well-made casein joints when dry are as strong as animal, vegetable starch or the blood albumins, and stronger than most varieties of wood. When wet, the highly water-resistant caseins are much stronger than either the untreated animal or the vegetable starch varieties. They are permanently durable under many conditions of change of humidity, and although they lose some of their strength when damp, they recover it when dry. Repeated exposure to wetting and drying, however, induces mould growths which attack and eventually destroy the adhesive. For further details see Chapter 3, "Moisture Resistance".

Caseins attain their maximum strength and heat and water resistance after 4 days.

Tendency to stain

Casein cements, being alkaline, have a tendency to stain certain woods such as oak, mahogany, maple, walnut, red gum, birch, beech, cypress, cedar, redwood and Douglas fir. The discolouration appears along the glue-line of joints and will penetrate through to the face of very thin or porous veneers.

The use of a thick mix and dry timber and veneer and the minimum pressure time reduces the tendency. When a stain has appeared, it may usually be removed by sponging with a solution of 1 oz. oxalic acid in about 12 ozs. of water. If this is not found to be entirely effective on a particular wood, it should be sponged first with a solution of 1 oz. sodium sulphate in 12 ozs. of water and then, while the wood is still moist, with the oxalic acid solution. The oxalic acid must be washed off carefully after removing the stain, as its presence may otherwise spoil subsequent finishing operations. Oxalic acid is a poison and should be used carefully.

Cleaning off and machining

Owing to the lime content, casein cements set particularly hard and impose heavy wear on cutters and saws. It is advisable, therefore, to trim panels and scrape surplus glue from joints before hardening has completed.

Machining of casein jointed woodwork should not take place for 8 to 12 hours after application of pressure, but it is advisable not to leave the operation much longer.

Cleanliness and skin protection.

Casein cements are practically odourless and do not decompose quickly, but all residue must be removed at the liquid or jelly stage from floors, benches and apparatus, otherwise it will be found impossible to do so without causing damage.

Casein cements irritate the skin and cause dermatitis unless precautions are taken. Workers whose hands come in contact with casein adhesives should be provided with protective gloves or barrier substances. Further information on this subject is contained in Chapter 16.

VEGETABLE-PROTEIN GLUES

The vegetable proteins are similar in preparation to the casein cements and are near akin in most properties. Instead of having casein as the protein constituent, they have as their adhesive base the residual meal or cake arising from the oil pressing of soya beans, peanuts or cotton seeds.

They differ in many respects from the vegetable-starch glues and are generally classified with the caseins.

They are used largely for the manufacture of plywood and laminboard on the west coast of America.

Like the caseins, they can be made fairly highly water resistant by the addition of chemicals. Carbon bisulphide is frequently added to the mix for this purpose.

They are not suitable for gluing thin veneers as their tendency to stain is even greater than that of the caseins. Neither have they proved satisfactory in the gluing of dense hardwoods.

Precautions must be taken against dermatitis when using these cements.

Special advantages claimed for these types of adhesive are :

(1) They can be used for the bonding of wood or veneer with as high a moisture content as 35 per cent. Re-drying of the glued stock will, of course, be necessary, but the total drying costs will be less than by following standard practice and the results are sufficiently good for low-grade work.

(2) The assembly time allowable between spreading and pressing is long.

(3) The handling of the coated core stock is simplified owing to the absence of extreme stickiness.

CASEIN-LATEX ADHESIVES

* Casein-latex adhesives, with varying percentages of casein and latex (natural rubber), are available for use where permanently flexible adhesives are required. Such conditions occur where it is desired to join two dissimilar materials having different ratios of heat or moisture expansion.

Typical cases are the bonding of wood to metal, plastics, rubber or linoleum.

Some manufacturers supply the casein powder and latex separately with full directions for mixing, whilst others supply the ready-mixed cement in solution.

Appendix to Chapter 7

U.S. FOREST PRODUCTS LABORATORY'S FORMULAE FOR CASEIN GLUES

Sodium silicate may be used as the sodium salt by those who are prepared to mix the various ingredients at the place where the glue is to be used. Casein glues so prepared differ from all the others. A much longer working life is obtained in a glue of a given alkalinity or, expressed in another way, much less sodium hydroxide need be introduced to obtain a given working life. Further, there is a considerable range of lime content (above that necessary to react with the sodium silicate) within which the working life decreases as the proportion of calcium hydroxide increases.

Several formulæ of the latter type have been developed at the Forest Products Laboratory. The best of these as yet is the following, which is covered by U.S. Patent No. 1,456,842, granted in 1923 to S. Butterman and C. K. Cooperrider (formerly of the Forest Products Laboratory) and dedicated to the public.

FORMULA 11

				Parts by Weight
Casein	..	..	..	.. 100
Water [1]	..	..	..	.. 150 to 250
Hydrated lime [2]	..	..	..	20 to 30
Water ..	..	..	..	.. 100
Silicate of soda [3]	..	..	..	70
Cupric chloride [4]	..	..	..	2 to 3
Water ..	..	..	..	.. 30 to 50

[1] The proper amount of water to use depends primarily upon the quality and ash content of casein and can be determined by mixing trial batches. With caseins containing about $3\frac{1}{2}$ per cent. of ash, 200 parts of water by weight is usually close to the proper amount. Since the ash content affects the water-taking capacity, it will prove convenient to secure a source of casein that is uniform in ash.

[2] The formula presupposes that a high-calcium chemical lime will be used. A low grade of lime often results in the presence of small lumps of lime remaining inactive and showing as small white spots in the finished glue-line. A lime lower in calcium may be used, but a proportionately larger amount will be required unless one is willing to sacrifice water resistance. It is suggested that the user try 25 parts of lime to begin with. If this does not give good results, the amount can be varied within the specified limits.

[3] The density of the silicate of soda used should be about 40 degrees Baumé with a silica-soda ratio of approximately 3·25 : 1.

[4] Cupric sulphate can be substituted for cupric chloride.

Method of mixing Formula 11

᙮ The casein and water are weighed into the bowl of the mixing machine and stirred sufficiently to distribute the water thoroughly throughout the casein. If the casein is ground to pass a 20-mesh screen it should be allowed to soak for some 15 to 30 minutes before proceeding with the preparation. If the casein is more finely ground the soaking period may be reduced. In a separate container the hydrated lime is mixed with water. This mixture is stirred vigorously at first, but just before it is added to the casein it should be stirred with a gentle rotary motion, just enough to keep the lime in suspension. With the mixer in operation, pour the "milk of lime" into the casein-water mixture.

When casein and lime are mixed they first form large lumps, which are balls of dry casein coated with partly dissolved casein. These break up rapidly, becoming smaller, and finally disappear. The solution, in the meantime, becomes somewhat thinner. A stirring device should be provided that insures thorough agitation. If a deposit of casein remains unacted on it may cause lumps later.

When about one minute has elapsed since the lime and casein were united, it will be noticed that the glue has begun to thicken a little. The sodium silicate must be added now, or the glue will be too thick. Disregarding lumps, if they are but few, pour in the sodium silicate. The glue will thicken momentarily, but the stirring should be continued until the glue is free from lumps. This should not take more than 15 or 20 minutes. If the glue is a little too thick, a small amount of water may now be added. If the glue is too thin, it will be necessary to start over again, using a smaller proportion of water; hence, it is important to make certain that too much water is not added originally.

Copper Salts improve Casein Glue

It has been found that copper salts added to casein glues increase their resistance to moisture and also make them more durable when exposed to the action of moulds and fungi.

In the preparation of copper-casein glue at the Forest Products Laboratory, 2 to 3 parts by weight of copper chloride or copper sulphate are dissolved in about 30 parts of water and are added to every 500 parts of the ordinary casein, lime and water-glass glue. The copper salt may be added at any one of several times during the mixing operation. If added as a powder before the casein is soaked, it may have a corrosive action upon the metal container.

The copper salt, if added as a powder, should be thoroughly mixed with the casein before the addition of the lime. Copper salt may be placed in solution and conveniently stirred into the moistened casein immediately before the lime is added or after all the other ingredients have been combined. If the copper solution is added at the end of the mixing period, pour it into the glue in a thin stream and stir the mixture vigorously. Continue stirring until any lumps, which may have formed by the coagulation of the glue and the copper solution, are broken up and a smooth, violet-coloured glue is obtained.

Glues containing little lime are especially improved by the addition of copper. A low-lime glue with copper may be as resistant to moisture as a glue with more lime in it, and copper does not shorten the "life" or period of workability of the glue so much as more lime would.

FORMULA 20

As indicated previously, a glue that will be exceedingly strong, but not at all water resistant can be made from casein, caustic soda and water. These ingredients are used in the following proportions:

					Parts by weight
Casein	..	..	..	..	100
Water ..	..	..	..	..	200
Sodium hydroxide (caustic soda)					10
Water ..	..	..	..		50

The casein and water are brought together as described in the directions for mixing *Glue 11*. Dissolve the caustic soda in water in a separate container, and while the paddle of the glue mixer is revolving add the caustic soda solution to the damp casein slowly until a thin smooth glue has been obtained. The consistency of the finished product may be altered by adding water if it is too thick or casein if it is too thin. The addition of casein, however, will necessitate considerable stirring to bring the added casein into solution and eliminate the lumps. Water-glass is sometimes added to thicken or to reduce the cost of the glue.

This glue has exceptional strength when dry, but when it is moistened it weakens as rapidly as animal or vegetable glue.

VEGETABLE-STARCH GLUES

Owing to the fact that at the time of writing vegetable-starch glues are not manufactured in this country and no data concerning them are available from home sources, the information contained in this chapter is drawn almost exclusively from publications of the U.S. Forest Products Research Laboratory.

ALTHOUGH adhesives made from starches and sugars are supposed to have been used by the Egyptians for sticking sheets of papyrus together, their commercial use in woodwork is recent and not common in this country. In the U.S.A., where the first patent was granted in 1896, the vegetable starches are used largely in the manufacture of plywood and are gaining popularity in furniture factories.

They are cheap, fairly simple to prepare and are used cold: three valuable qualities. They also have unusually long working life, only need light pressure and are very slow-setting. The first two properties are advantages in certain manufacturing processes, but the slow setting is a disadvantage, particularly in such operations as edge-jointing. Although they are being improved steadily, so far these glues suffer limitation of use from their lack of moisture resistance.

Starch is the principal form in which plants store their reserve food and sources of supply are abundant in the vegetable world. Starch occurs in a high degree of purity in the stems of the sago palm and the banana, in seeds such as maize and corn, and in certain roots such as the potato and cassava (tapioca). Cassava starch is noted for the consistency of its paste and is the variety most commonly used in the manufacture of vegetable glues. To those with childhood memories of tapioca puddings, it will come as no surprise to learn that cassava (tapioca) is at last recognised as a strong adhesive!

Most of the commercial cassava is grown on plantations in Java, though the plant, which is a woody shrub growing to an average height of 10 to 12 ft., is said to have originated in Brazil.

The starch is obtained from the roots and is processed in order to:

(*a*) make it more soluble, by modifying the outer wall;

(*b*) reduce its water absorbing propensity so as to create an adhesive of low water content;

(*c*) produce a uniform product.

Most of the processes used in manufacture are secret or patented and finally deliver the glue to the user in powder form.

Tests

There are, at present, no generally accepted chemical tests which will indicate the value of a given starch as a raw material for glue making; reliance must therefore be placed upon joint tests in determining the quality of starch for glue making.

Although a considerable amount of research has been carried out on starch, there is not yet agreement on such fundamentals as the nature of the starch grain and how it changes into glue.

Preparation

Whatever method of pre-treatment of the starch is adopted by the manufacturer, the preparation for use of the adhesive is carried out in one of the following ways:

(1) By adding caustic soda and then heating. Usually about 3 per cent. caustic soda, based on the weight of the dry starch, is dissolved in approximately three times its own weight of water, added to the starch/water mixture and heated to approximately 150° F. (65° C.).

(2) By adding caustic soda without heating. In this method of preparation, the amount of caustic soda is usually about 7 per cent. but may vary from 6 per cent. up to 10 per cent. of the weight of the dry starch; it is dissolved in about three times its weight of water and added to the starch/water mix without heat.

(3) By heating alone. The starch/water mix is converted into glue by heating to 150° F. (65° C.) for 1 hour. No caustic soda is added.

The glue produced by method (3) is more like a paste than a glue and lacks the stringiness which is characteristic of starch/caustic-soda mixes; nevertheless, it produces satisfactory joints and does not stain. Its disadvantage is short working life.

The addition of the caustic soda creates advantages and disadvantages. It adds to the working life, slows the "set", necessitating longer time under pressure, while the more alkaline

it becomes, as the soda content increases, the greater is the inclination to stain those varieties of wood listed in Chapter 7, "Caseins" (Tendency to stain).

Method (1) seems to represent the middle course and retains the maximum of the advantages with the minimum of the disadvantages. In consequence, it is the most popular general purpose mix.

Method of mixing

Owing to the high viscosity of this type of glue, a mechanical mixer is essential and when heat is used, as in mix 1 described below, the steam-jacketed type of mixer gives the best control.

Firstly, the required amount of cold water is poured into the mixer, then the dry starch is added slowly and stirred until a uniform consistency is reached. The starch-to-water ratio varies from 1:1.25 in the case of some highly processed starches, to 1:4 in the case of raw starches. This difference clearly shows how the processing of the starch reduces the water absorption. All manufacturers give clear instructions for starch-to-water ratios.

At this stage the caustic soda (previously dissolved in three times its own weight of water) is added and stirred in slowly and thoroughly. Steam is now turned into the outer jacket of the mixer until its temperature is approximately 200° F. (93° C.), which will give an average temperature of 150° F. (65° C.) to the starch suspension in the inner container. The heating should continue only until the mixture changes from white to an amber coloured and almost translucent, stringy paste. Emphasis is laid on the immediate reduction of heat when the amber-coloured, stringy-paste stage is reached, because overheating of the starch suspension produces a chemical change usually known as caramelisation. It is characterised by a reddish-brown discoloration of the paste and a reduction in its adhesive power. It is guarded against effectively by:

(*a*) adding the caustic soda to the starch prior to the application of heat;

(*b*) controlling the temperature carefully during the conversion of the starch;

(*c*) reducing the temperature immediately the amber-coloured, stringy-paste stage is reached.

Immediately this takes place, which is usually at the end of about half an hour, the hot water in the jacket should be replaced by cold and the heat of the mixture reduced to room temperature, stirring continuing all the time.

The glue is now ready for use and may be stored for several days without serious deterioration, though some changes in viscosity will take place.

. Caustic-free glues become more viscous after standing, whilst those with a high percentage of caustic soda thin appreciably.

Application

Vegetable-starch glue is too viscous for hand or spray application and must be used on a mechanical spreader.

Working life and spread

Vegetable-starch glue has a working life of many days and any residue from the day's run may be left in the spreader over-night, covered with a damp cloth and used next day.

The usual spread is in the nature of 45 to 50 sq. ft. per lb. of dry glue. A much thinner spread results in weak joints and a much thicker one tends to introduce too much water into the gluing operation.

Rate of set and pressure

The vegetable starches have the advantage of being light-pressure adhesives. The maximum pressure used is 200 lbs. per sq. in. and then only when the assembly time is abnormally long, such as between 20 minutes and half an hour. For assembly periods of 10 to 15 minutes, pressures of 125 to 150 lbs. are usual; if the assembly time is 5 minutes or less, pressure of 100 lbs. gives good results. Veneered stock and plywood require to be kept under pressure about 12 hours and should then be left for further drying and conditioning before machining. The joint strength of vegetable-starch adhesives develops more slowly than that of caseins or animal glues.

Water resistance

This is low and limits the use of vegetable-starch glues to interior and moisture-protected work.

Tendency to stain

The tendency to stain is nil in the case of the caustic-free mix, but increases in direct ratio to the amount of caustic soda added.

Cleaning off and effect on tools

The caustic-soda content tends to harden the glue-line, but provided the cleaning off of surplus glue and machining takes place within 2 or 3 days of gluing, there is no undue wear on the cutters.

Cleanliness and skin protection

The vegetable-starch glues are clean, free from odour, slow to decompose, easy to remove from floors, benches and apparatus.

When the mixture used contains caustic soda, gloves or barrier substances must be provided for the operators in contact with it.

BLOOD-ALBUMIN CEMENTS

Prior to the 1914-18 war, blood-albumin cements were but little used. It was the need for high moisture-resistant adhesives for aircraft and boat construction that brought them into prominence in Europe and America.

The major advantages of these varieties of adhesives are the very high moisture resistance of some of the formulæ (see Chapter 3: "Moisture Resistance", page 28); their quick setting and negligible dulling effect on tools; the fact that they do not show through a thin or porous veneer; that most of the formulæ have no irritant effect on the skin. They are, in fact, the only highly moisture-resistant adhesives which are not liable to cause dermatitis.

They are used chiefly in the manufacture of highly water-resistant plywood in America, and prior to the development of the synthetic-resin adhesives, they were the nearest approach to a waterproof cement that was available. Originally a hot-press adhesive only, blood albumin is, thanks to the U.S. Forest Products Laboratory, now available in a formula that can be cold pressed. In this form, it has considerable advantages, but does not make such strong joints as when hot pressed.

There is also now on the market a hybrid, blood-abumin and synthetic-resin adhesive, that is used in the hot-press manufacture of Douglas fir plywood of "exterior grade". The formula for this is given in Chapter 10, page 97.

The disadvantages which limit the commercial use of the blood albumins are: difficulties of supply, the extreme care necessary in preparation and the comparatively low dry strength in the cold-press mix. These limitations combine to make the blood-albumin based adhesives unsuitable for general woodworking purposes, such as jointing, and only advantageous for veneering and ply-wood manufacturing, where high moisture resistance is a valuable consideration. The difficulties of supply were mainly due to the large number of very small slaughter-houses in use before the war; if the wartime concentration into a small number of large

units is continued now, difficulties of supply should largely disappear.

Basis and manufacture

The constituents of blood-albumin cements are mixed at the time of use and not offered for sale in dry, ready-mixed form, as are most other adhesives. This is chiefly because of the decrease in solubility of the blood albumin with age.

The blood albumin used in adhesives may be obtained either from the fresh blood of slaughtered animals or in a dried, soluble form which has been processed from fresh blood.

The rapid decomposition of fresh blood makes the use of the dried solution the easier and more general method. It is obtained by clotting the blood in tanks, removing the fibrin and part of the red corpuscles and evaporating the residue until dry.

Tests and requirements of blood albumin

Dry blood albumin is seldom bought in accordance with a definite specification and no standard tests have been devised. If it is to make up into a satisfactory adhesive, it should certainly pass the following tests.

(1) It must be 90 per cent. soluble.
(2) It must be relatively free from entrained air, otherwise the cement will be frothy and weak.
(3) The fat content must not exceed 1 per cent.
(4) The ash content must not exceed 10 per cent.
(5) The moisture content must not exceed 8 per cent.
(6) After meeting these requirements, it is still advisable to mix some of the albumin into cement and test some trial joints made from it before embarking on large-scale production.
(7) Blood albumin, light or dark in colour, may be equally satisfactory; colour bears no relation to strength.

Mixing and application

(1) All materials should be weighed, not measured.
(2) Whatever formula is being used, the blood albumin if dry has to be put back into solution. This is accomplished by soaking it in clean, cold or tepid water for 1–2 hours. After this, it should be stirred slowly until it is uniformly consistent. If it contains

much soluble matter, it should be strained through a 30-mesh screen.

(3) Blood-albumin cements are particularly prone to frothiness, which results in joint weakness. To avoid this, stirring must be neither excessive nor too rapid; if a mechanical spreader is used, it should be run slowly and stopped when not required. Application may be by spreader or brush.

Pressing

(1) Press temperatures in excess of those recommended must never be used, otherwise blistering will result.

(2) When using the hot process, the panels should remain in the press sufficiently long for the cement to attain a minimum temperature of 160° F. (71° C.) over the whole surface.

(3) Heavy pressure is not necessary with this type of adhesive; 100 to 200 lbs. per sq. in. gives satisfactory results.

Formulæ

An adhesive may be made from blood albumin and water alone; usually, however, alkali and other materials are added to increase adhesive properties and moisture resistance.

By kind permission of the U.S. Forest Products Laboratory, two of their formulæ are given in the appendix to this chapter. The first is for a hot or cold wet-process cement (glue) and the second is for a dry cement (glue) formula, which has advantages for certain manufacturing processes.

Appendix to Chapter 9

U.S. FOREST PRODUCTS LABORATORY'S FORMULA FOR BLOOD-ALBUMIN GLUES

(1) Water-Resistant Cold or Hot-Press Paraformaldehyde-Blood-Albumin Glue

A formula and method of preparation for a highly water-resistant blood-albumin glue developed at the Forest Products Laboratory is given below:

100 parts by weight of soluble blood albumin.

140 parts to 200 parts by weight of water (according to consistency desired).

5½ parts by weight of ammonium hydroxide (sp. gr. 0.90).

15 parts by weight of paraformaldehyde.

Paraformaldehyde is a polymer of formaldehyde and not a definite chemical compound. Its properties will vary somewhat depending upon details of the manufacturing process. A "slow reacting type" is required for use in this formula. It is advisable, therefore, to purchase the paraformaldehyde directly from the manufacturers and to specify the "slow reacting" type suitable for use in glue formulæ.

The blood albumin is covered with the water and the mixture is allowed to stand for an hour or two. Then, when the mixture is stirred, the blood albumin will for the most part go into solution. The ammonium hydroxide is now added with more stirring. The paraformaldehyde may be conveniently added in the form of a suspension in water; just enough water being added to the paraformaldehyde powder to form a "milk." This suspension is poured into the mixing bowl during continued stirring. Preliminary thickening is a characteristic of this type of blood-albumin glue and usually takes place within 5 minutes after the paraformaldehyde has been added. The stirring should be continued until the mixture turns to a thick mass, which is then allowed to stand until thinning occurs. The thickened glue ordinarily returns gradually to a good working consistency in about 1 hour. It will remain in this condition for about 6 or 8 hours, after which it sets to an insoluble jelly. Care should be taken to remove the glue from the mixer and spreading equipment before final setting takes place, otherwise difficulty in cleaning will be experienced.

Application and Pressing

The glue may be applied by means of a brush or mechanical spreader. It may be used cold on the lighter weight woods or where high strength of joint is not essential, but the application of heat is required to produce joints of uniformly high strength and to develop the full advantages of the glue. When cold pressed, the gluing is done in the same manner as with casein or vegetable glue and with the same equipment. Hot pressing, however, improves the joint strength and water resistance and is recommended as a general practice. If the panel is hot pressed, it should be

left under pressure a sufficient time for all parts of the glue joints to attain a temperature of 160° F.[1] There are indications that higher temperatures (up to 300° F.[2]) and longer periods of pressing (up to 30 minutes) will produce even better joints.

The glue when hot pressed has shown exceptionally good water resistance and durability under extreme exposure in laboratory tests and in this respect is superior to earlier formulæ. Equally good results have been obtained by hot pressing promptly after spreading or by pressing cold, allowing the panels to remain under pressure overnight, and hot pressing on the following day. The second method reduces to some extent the difficulties from blistering when the platen temperatures are in excess of 212° F.[3]

(2) A Dry-Glue Formula

A hot-press blood-glue formula[4] has been developed at the Forest Products Laboratory that offers advantages for certain special uses. The formula is as follows:

				Parts by weight
Black soluble blood albumin			..	100
Water ..	..	..	..	190
Hydrated lime	..	..	..	1·5
Water ..	..	..	..	10
Sugar syrup ..	..	..	..	60 to 100

The combination of materials follows the same general procedure as in other formulæ used in mixing blood glues for plywood manufacture. The syrup is added to make the glue sufficiently hygroscopic to permit adhesion to the wood if the glue film is dried before pressing. Corn syrup gave good results, but an invert sugar gave even more satisfactory results. The quantity of syrup depends on the kind used. Glycerine may be substituted for the sugar, but a smaller quantity is required.

It was originally intended that this glue be spread on both sides of a thin porous paper, dried, and used in the form of a thin film[5] in much the same manner as the more recently developed film glues of artificial resins. The formula lends itself, however, to another technique that might prove useful in certain gluing operations. The crossbands or the crossbanded cores may be

[1] 71° C.   [2] 149° C.   [3] 100° C.

[4] This glue is covered by U.S. Patent No. 1,336,262, granted to Sponsler, Dunlap and Henning and dedicated to the free use of the public.

[5] A dry-glue method of laying veneers, by T. R. Truax. *Veneers,* Oct. 1930 (mimeographed copy No. R914 available from the Forest Products Laboratory, Madison, Wis., on request).

spread directly with the adhesive (without employing the paper carrier) and allowed to dry. The coated surfaces should be exposed to a damp atmosphere for a few minutes or otherwise moistened slightly before gluing, the plies laid together, and the assembly hot pressed. Since very little water is present in the glue-line at the time of pressing, dangers of blistering are largely eliminated.

Chapter 10

SYNTHETIC RESIN CEMENTS

IF your motto is "near enough" do not read this chapter, for the synthetic resins will not help you. They are the precision adhesives and most of them will refuse to perform under "near enough" conditions. Given the right treatment, though, there is at least one variety among them suitable for each woodworking purpose and some wood construction needs which are fulfilled by no other adhesives.

The synthetic resins are first and foremost the chemist's gift to the woodworking engineer; in fact, they have contributed largely to bringing the modern woodworking engineer into being.

The term "synthetic resins" arose from the general resemblance in appearance of the synthetic chemical compounds to some of the natural resins. It now covers a wide range of products, many of which bear no resemblance to natural resins and some of which are not yet of practical interest as adhesives.

It is incorrect to call the synthetic resins waterproof in the sense that one thinks of a mackintosh, inasmuch as their film or glue-line is not impervious to moisture; their strength, however, is but little affected by its penetration and, in fact, they are insoluble. With the possible exception of some of the blood-albumin formulæ, the synthetic resin groups are the only ones which, as detailed in Chapter 3, contain adhesives capable under conditions of alternating immersion in water and drying out or, alternatively, extemes of high and low humidity, of retaining over a period of years sufficient of their dry strength to withstand the violent stresses set up in the wood by these changes.

These adhesives are also immune from mould growths and certain of them will withstand heat that will destroy adhesives of nearly all other groups.

It is significant that the violence of the long-term moisture-resistance tests to which synthetic resins have been subjected in the United States is such that it has produced decay in the wood before it has lowered the strength of the glue joint to the same degree. It follows automatically, therefore, that the synthetic

resin adhesives have opened up a completely new field for glued-wood joints in marine, aircraft and building engineering and in general construction which is subjected to violent change either of temperature or of humidity. Exterior construction that can rely on glue for jointing must inevitably add to the uses of wood and minimise its waste.

All the synthetic resins are useful for primary gluing—that is, manufacturing of plywood (of exterior grade). Some are equally good for building up laminated beams or trusses or for forming the complicated curves and other sections which occur in aircraft, shipbuilding, etc.

Most varieties of synthetic resins, however, demand careful control of mixing, application, heat and pressure, as well as a narrow limit of wood-moisture content and precise machining.

The first record of an attempt to use a phenolic resin as an adhesive for plywood appears to be a British patent taken out in 1901. In 1910 a Frenchman took out a patent on the same line, but no phenolic-resin adhesive seems to have reached the commercial stage before or during the 1914–18 war, in which aircraft plywood was glued with casein or blood albumin. Between 1920 and 1935 considerable work was done on synthetic resin adhesives and they were brought to the commercial stage, though at first high cost and shortage of hot presses limited their development.

Like all new products, they had their teething troubles, and the worst was that they were liable to crack or craze some time after the joint was made. This weakness has now been overcome entirely, provided the adhesives are used as a thin film to join surfaces which are machined to fit accurately together.

Synthetic resins are not "gap filling"—that is, they cannot be used to compensate for inaccuracy in the fit of joints—*except those compounds which are specially formulated as gap-filling adhesives*. Non-gap-filling synthetic resin adhesives when used as gap fillers—that is, in thick layers—"craze" and the joints formed with them soon deteriorate.

The Two Main Groups

On the basis of physical properties, the synthetic resin adhesives fall into two main groups, known respectively as thermo-setting and thermo-plastic. Each group contains numerous varieties.

The condensation reaction or "set" of the thermo-setting

group, when once completed is irreversible, and no subsequent softening occurs even if the temperature is increased beyond the original setting temperature. The thermo-plastic adhesives, on the other hand, soften again when the temperature passes beyond the heat range characteristic of each type of resin. For this reason and because the glued stock has to be cooled under pressure, so slowing down production, the thermo-plastics are not nearly as widely used in woodworking as the thermo-setting adhesives.

THE THERMO-SETTING CEMENTS

The best known of the synthetic resin adhesives are all thermo-setting. They are:

(1) Those produced by a condensation of phenol or cresol and an aldehyde, usually a formaldehyde—that is, the phenol formaldehydes.

(2) Those produced by a condensation of urea and formaldehyde.

(3) Those produced by a condensation of melamine and formaldehyde.

The Phenol Formaldehydes

The phenol formaldehydes may be purchased in many forms, as will be seen from Chart 1 at the end of this chapter, p. 108. They first appeared as alcoholic solutions, but were soon made available and became popular in Germany in the film form under the name of "Tego Gluefilm". They are now produced in this country by British Tego Gluefilm, Ltd. Later, powders for mixing with water or spirit and sometimes an accelerator or hardener at the time of use were introduced.

Most, but not all, of the phenol formaldehyde adhesives are of the hot-pressing variety and create joints so strong that, even under the tests designed by the British Standards Institute to cover resistance to boiling water and cold water, it is impossible to break them without destroying the wood first. There are a number of different British Standard Specifications covering the varieties of synthetic resin adhesives and also applicable to specific uses. Application should therefore be made to the British Standards Institute for details.

Phenolic-Film Adhesives

Phenolic-film adhesives consist of thin sheets of very absorbent tissue paper, coated and impregnated with phenolic resin and dried and wound into roll form. The glue film consists of approximately one part of paper and two parts of resin by weight and its thickness is of the order of 0·004 in. The rolls may be of any width up to 6 ft. 6 in., and should be stored in a dry, cool room and kept upright, otherwise the pressure may create waste by causing the layers to adhere to each other. Rolls should not be stored for more than about twelve months and it is advisable to check the adhesive properties after this time.

Because heat as well as pressure is necessary, not only to make the resin fluid and force it into the wood but also to set it finally, the use of film adhesives is limited almost entirely to primary gluing—that is, to those processes where it is practical to transmit the heat to the glue-line. Improved methods of heating which are described in Chapter 15 are increasing steadily the scope of film uses. So far plywood, with its layers of thin veneers, has proved the most important field of application for this form of adhesive.

Plywood made from well cut and correctly dried veneers and bonded in accordance with the instructions of the manufacturer of this type of adhesive approaches as near to perfection as it can and has less tendency than any other to warp, split or delaminate. This is chiefly because this process adds little if any moisture to the veneer at the gluing stage and because of the high strength and moisture and fungus resistant nature of the bond produced.

The invention of the film type of adhesive has done more to clean up gluing than has any other single factor, and where it can be used there is no need for mixers, glue-pots, brushes, spreaders or spray-guns; the only instrument required is a pair of scissors for cutting the required size and shape of sheet from the roll. There is no variation in the spread and the adhesive is like a clean and magic carpet, placed between the veneers which it bonds on application of heat and pressure. Apart from cleanliness and the high degree of control of the gluing operation afforded by film adhesives, they also offer ease in handling and storage and no limit to the assembly period. The films are expensive, but the cost is justified for certain processes of manufacture where especially severe service conditions are entailed.

When using film adhesive, it is essential that the surface of the veneer be smooth and evenly cut, because the amount of

glue cannot be varied to compensate for inequalities or roughness.

Moisture content of the veneers must be controlled rigidly within the limits set by the film manufacturers. For most woods and purposes the range varies between a "low" of 7 per cent. and a "high" of 10 per cent. Much higher moisture contents are liable to cause blisters.

The Platen Temperatures

The platen temperatures generally recommended for phenolic-film adhesives are from 280° F. (138° C.) to 310° F. (154° C.), the upper temperature being preferred to shorten the time in the press and reduce the time-cycle of a load.

Time in the press

There is variation in the pressing time according to the distance from the hot platen to the furthest glue-line, the density and moisture content of the wood and the brand of film which is being used, but a basic time of 3 minutes in the press, with an addition of $1\frac{1}{2}$ minutes for each millimetre of board thickness, is about the average.

The bonding pressure

This varies according to the density of the wood, and whilst it is true to say that increased pressure improves bonding with non-gap-filling adhesives, such as the films, this only applies provided the pressure remains within the crushing strength of the wood. The pressure should be sufficient to compress the assembly 5 or 10 per cent. and force close contact between the heat-softened resin and the wood. For birch, beech or oak, a pressure of 200 to 300 lbs. is needed, but for spruce, yellow poplar, gaboon or obechi, 100 to 150 lbs. per sq. in. is sufficient. It is because of the necessity for conveying the heat to the centre of the panel that the time in the press has to be increased for thicker panels. In ordinary hot presses, 1 in. thickness has so far proved about the practical limit of thickness for plywood bonded by this method. The newer methods of heating discussed in Chapter 15 should remove this limit.

Conditioning

After removal from the press, the panels must be allowed to cool uniformly and re-absorb moisture. In some processes, they

are sponged or submitted to steam to bring them back to the desired moisture content.

Hot-press Liquid Phenol-Formaldehyde Cements

Hot-press liquid phenol-formaldehyde cements are sold as:

(1) liquid adhesives ready mixed;

(2) liquids to which catalysts or hardeners are added immediately before spreading;

(3) powders for dissolving and mixing in water, commercial denatured alcohol or a mixture of water and alcohol.

Generally, water solutions consist of about 40 per cent. solids and water–alcohol solutions of about 60 per cent. solids. In the case of solutions in which alcohol forms part or the whole of the solvent, the drying time is shortened, but so is working life, both in the mixer and spreader, due to evaporation. Alcohol adds to the cost of the mixture and makes machine cleaning more difficult. Alcohol solutions are particularly useful for softening brittle veneers.

When not purchased ready mixed, the instructions of the manufacturer as to method and proportions must be carefully followed.

The working life

The working life of these mixtures when exposed to the air may vary from half an hour to several days. It should be remembered that with synthetic resins of this type, heat completes the "set", so that a high workshop temperature shortens the useful life of the mixture. When stored in liquid form, the containers holding the mixture should be kept sealed and in a cool place.

Application

Application may be carried out by brush, but an ordinary resin glue spreader, preferably with slightly ribbed rubber rollers, gives more even results and is the usual method employed. Spray-guns are sometimes used, when there are advantages and when the mixture is not one with too short a life. All apparatus must be cleaned frequently, preferably with cold or tepid water and before there is any risk of the adhesive setting into a hard, insoluble mass.

Moisture content

The moisture content of the veneer at the time of pressing is most important and for most brands of adhesive must not exceed 12 per cent. To keep within this figure, the moisture content of the veneer before application of the liquid adhesive should be between 3 and 5 per cent. and it will be necessary to leave the veneers to dry out for an hour or longer after completion of the spreading.

The amount of moisture introduced by the adhesive is relatively high and blisters, starved joints, excessive penetration and the necessity of extended curing time after pressing may all be consequences of failure to allow sufficient time between spreading and pressing for reducing the moisture content of the veneer to under 12 per cent.

Pressure, platen temperatures and times in the press cover approximately the same range that has been given already for the phenol-formaldehyde film adhesives.

Most hot-setting phenolics are mildly alkaline.

Extenders are not used largely with phenolic-resin adhesives, but some hot-setting phenolics may be cheapened by extending with starch and will prove perfectly satisfactory for many purposes. In the United States walnut-shell flour is sometimes used to control flow and penetration. All such extension reduces wet strength and resistance to attack by micro-organisms. An appreciable amount of extenders also decreases the permissible assembly time, shortens pressing time and increases the necessity for careful control.

Phenol-Formaldehyde and Blood-Albumin Cements

Latterly, some phenol-formaldehyde cements have been formulated for extension with blood albumin. The development is an interesting one, the resultant cement being highly water and mould resistant, cheaper than the pure phenol formaldehydes and, though still a hot-pressing adhesive, the temperature required is some 60° F. less than that needed for the pure phenolic resins. So far, this type of adhesive has been used mainly in the United States for the manufacture of exterior grade Douglas fir plywood. The adhesive is a dark, reddish brown in colour.

In a popular brand the phenol-formaldehyde resin and the dried animal blood are both supplied in powder form and are dissolved separately in cold water. They are then blended together and a powdered catalyst, which has been dissolved in warm

water and allowed to cool, is added. The proportions of the dry materials are as follows:

Resin	90 lbs.
Dried blood	100 lbs.
De-foamer	2 lbs.
Catalyst	$\frac{1}{4}$ lb.

These proportions must not be varied, but the total weight of water, which always exceeds that of the solids, will vary somewhat according to conditions.

At an early stage during the process of mixing, a very acute thickening occurs, but continuation of the mixing thins the mixture down to a usable consistency. This it retains for a normal working day. It may thicken again after standing for a short while, but it will thin down when stirred.

Application

The cement is applied by spreader, and here again it may appear very thick in the trough when the spreader is stopped, but it will thin rapidly when the spreader is in action. The permissible gluing time which may elapse between the spreading of the cement on the veneers and the application of full pressure must not exceed 12 minutes. The cement must be damp when it enters the press and this is impossible if the veneers are too hot. Their temperature, therefore, should not exceed 100° F. (38° C.). When the press is loaded, it must be closed to full pressure within 1 minute.

The press temperatures

Press temperatures may vary between 230° F. (110° C.) and 245° F. (118° C.) and time in the press from $3\frac{1}{2}$ minutes for $\frac{3}{16}$-in. panels, up to 8 minutes for 1-in. panels.

Low-Temperature Liquid Phenol-Formaldehyde Adhesives

These are sometimes known as cold-bonding resins or cold-setting phenolics, but both are rather misleading terms. Actually they are adhesives formulated for bonding in low-temperature presses—that is, those with a range up to approximately 212° F. (100° C.).

All such adhesives are used in conjunction with a catalyst, which is added and mixed in immediately prior to use.

7

The working life

The working life of these low-temperature phenols is rather short. The mixture when completed thickens up slowly and remains usable for anything from 2 to 6 hours, the time varying according to the room temperature and, to a lesser degree, according to the percentage and variety of catalyst that has been added. The life of the mixture is shortened by a high temperature, and the higher it is, the less will be the amount of catalyst needed.

Press temperatures

Press temperatures in this process generally vary between 140° F. (60° C.) and 212° F. (100° C.). With a press working around 212° F. (100° C.), the pressing times are approximately the same as those given for the hot process, but time in the press rises steeply as the temperature falls, and when working around 140° F. (60° C.) the time required in the press may be three to four times as long.

Most adhesives of this type are gap fillers.

They are strongly acid and can only be mixed in stainless steel, chrome-plated, nickel-plated, enamelled-iron, earthenware or wooden containers or waxed-paper cartons. Spreading may be carried out by brush or roller.

The Urea-Formaldehydes

The urea-formaldehydes suffer from a popular misconception that they are not as strong as the phenolics. In fact, they possess just as high dry-joint strength and when not extended with undue amounts of starch, wood flour, etc., their mould resistance is also as great.

They have fairly high damp or water resistance, but are inferior in this respect to the phenolics and will not stand up nearly as well to boiling tests. They weaken rapidly if they are soaked in water much above 150° F. (66° C.).

The urea-formaldehydes are formulated both for hot-and-cold pressing. In both processes they possess the advantage of being pressed at correspondingly lower temperatures than the phenolics.

Special formulæ have been developed for specific purposes, such as edge-jointing of veneers and for gap filling. With the latter, reasonably strong joints may be made with cement lines as thick as 0·04 in.

As stated in the opening paragraphs of this chapter, synthetic resin cements are not gap fillers unless specifically formulated for this purpose. To overcome the drawback of "crazing" in thick cement lines, two avenues of research have been explored. The first, in which plasticisers are incorporated to render the cements more flexible, has so far not yielded entirely satisfactory results in mixed glues, though cements with a combined plasticiser and hardener have been produced for use by the separate application method. Most gap-filling cements at the present time have been developed from the second avenue of research, which is reliance on the addition of fillers.

Where high water resistance is not required, the addition of these fillers has several advantages. The ones most usually employed are starch in the form of rye flour or wheat flour, wood flour which will pass through a B.S. 240-mesh sieve, tapioca, finely divided cellulose fibre or blood albumin, etc. Whilst these fillers or extenders lessen mould resistance and lower water resistance still further, they not only make the cement gap filling but they also cheapen production costs and are no drawback in certain indoor manufactures, such as furniture, where very high water resistance is not needed under polish or paint.

The instructions of the manufacturer should be followed carefully as to the type of extender to use with a particular brand of resin and as to the permissible amount because, apart from the points already mentioned, its addition also makes some reduction in the shearing strength of the dry joints, and therefore should not be carried to excess.

When using porous veneers the addition of an extender has the advantage of reducing penetration and may improve the working qualities of the adhesive.

Another and very ingenious manner of reducing gluing costs without any sacrifice in moisture or mould resistance, has recently attracted considerable attention in this country. The method, which has been practised on the continent for some years, takes advantage of the tendency of most liquid adhesives to foam during the mixing and develops controlled foaming by means of a specially designed machine, so that the volume of the adhesive is doubled by being whipped up into a cream which really consists of one-half adhesive and one-half air bubbles of so minute a size as to be almost invisible. The spread of adhesive, in lbs. per sq. ft., is accordingly halved. Nevertheless, for normal

commercial plywood, made up of good-quality veneers and bonded under sufficient pressure, the adhesion is adequate and for veneering, particularly with porous decorative veneers, there is the advantage that very little moisture is introduced and, in consequence, there is minimum risk of percolation through the face of the veneers.

Although they are not marketed in sheet film form like the phenolics, the urea-formaldehydes are supplied in so many other ways that they are apt to prove confusing to the intending purchaser.

These varieties and their methods of application are set out clearly and separately under hot- or cold-pressing varieties and Charts 2 and 3 at the end of this chapter provide a quick reference. Frequently the same cement may be used for hot or cold pressing, the difference being only in the catalyst or hardener.

The Hot-Pressing Varieties (see Chart 2 p. 108)

These are usually non-gap-filling. They may be purchased in the form of:

(1) Dry powder consisting of the urea-formaldehyde resin and the hardener, ready mixed for dissolving in water.
(2) Urea-formaldehyde resin in syrup form, for mixing with liquid hardener.
(3) Urea-formaldehyde resin in syrup form for mixing with powdered hardener.

Mixing

Where this has to be carried out by the user, the instructions of the maker will be found simple to follow.

The working life

The working life of most mixtures when exposed to the air is at least one day.

Application

Hot-press ureas are applied thinly, generally to one surface only. The best application is by a mechanical spreader with ribbed rubber rollers. This type of adhesive is sufficiently thin to use by hand methods and does not attack brushes, but application by brush is slow and difficult to carry out as evenly and thinly as is desirable.

Press temperatures

Those advocated are mostly between 194° F. (90° C.) and 212° F. (100° C.), with a few manufacturers preferring up to 230° F. (110° C.). The strength of the joint is improved by using the highest temperature of the range given by the manufacturer.

Pressure requirements

Pressure requirements vary considerably with different formulations. Some only require hand pressure—that is, 30 lbs. to 40 lbs.—others need 100 lbs. to 200 lbs. per sq. in. Time in the press, as with the phenol formaldehydes, depends on the variety and moisture-content of the wood, together with the distance between the platen and the furthest line of adhesive. The basic time may be anything from 3 to 5 minutes, plus 1 minute for every millimetre of thickness.

Conditioning

When hot-pressed urea-formaldehyde cements are used entirely without or with only small quantities of extenders, the panels come from the hot press at a lower moisture content than they will obtain subsequently and a conditioning period must be allowed. It is not advisable to moisten the panels to speed up this process.

The Cold-Pressing Varieties

The cold-pressing varieties of urea-formaldehyde cements set at normal room temperatures, and in consequence are particularly useful for secondary gluing—that is, woodwork assemblies. They include gap-filling and non-gap-filling varieties and they may be purchased in the form of:

(1) Dry powder consisting of the urea-formaldehyde resin and the hardener, ready mixed for dissolving in water. ·

(2) Urea-formaldehyde resin in dry powder form for mixing with liquid hardener.

(3) Urea-formaldehyde resin in syrup form for mixing with liquid hardener.

(4) Urea-formaldehyde resin in syrup form for mixing with liquid hardener plus filler (the last item being an essential part of the mix).

(5) Urea-formaldehyde resin in syrup form and liquid hardener for the separate application method.

(6) Urea-formaldehyde resin in dry powder form for dissolving in water or spirit and for use by the separate application method in conjunction with a liquid hardener.

Most of the varieties may be extended with starch, such as rye flour, but only in such formulations as (4) is the extender an essential part of the mixture.

In order to set the urea-formaldehyde resins without the application of heat, it is necessary to introduce a strongly acid catalyst or hardener, and this restricts the working life of the mixture. The rate of this setting reaction and therefore the time in the press, as well as the pot life, vary not only according to the strength and variety of the hardener but also according to the glue-room temperature and that of the wood. Most of the cold-pressing urea-formaldehyde mixtures are formulated to set at temperatures ranging between 50° F. (10° C.) and 80° F. (27° C.). A few will set at a temperature as low as 40° F. (3° C.). Although the specific application of heat is not needed to cause the set, it does accelerate it, sometimes too much, making the working life too short to be practical. To assist in overcoming this difficulty in warm weather, the container in which the mixed cement and hardener are placed is sometimes surrounded by a bath in which cold water is circulated. Alternatively, an ice jacket is used.

Where layout will permit, it is useful to be able to do the actual gluing in a cool room and then pass the work into the press or clamps in a hot room, where speedy setting will take place.

Whilst there is considerable variation between different formulations, a mixture which has a working life of 6 hours at 70° F. (21° C.) will probably be usable for only 3 hours at 80° F. (27° C.), 1½ hours at 90° F. (32° C.) and ¾ hour at 100° F. (38° C.).

It is usual for a single variety of urea-formaldehyde adhesive to be sold for use with three different speed hardeners—slow, medium and fast. These hardeners are often dyed in different bright colours to avoid confusion. How wide a range of times these hardeners cover is shown by their effect on a well-known brand of urea-formaldehyde resin. The times given are

approximately the same for the pot life and for the minimum time in the press.

Temperature	Fast Hardener, hours.	Slow Hardener, hours.
80° F. (27° C.)	$\frac{1}{2}$	2
70° F. (21° C.)	1	3
60° F. (16° C.)	$1\frac{1}{2}$	6
50° F. (10° C.)	2	8
40° F. (3° C.)	4	14

The above is rather a quick setting range; some are much slower and at the lowest temperature and with the slowest hardener may have a pot life as long as 35 hours and require a correspondingly long time in the press. A few brands are sold with one hardener only and the rate of set is varied according to the proportion of hardener to urea-formaldehyde resin.

The separate application method, referred to under headings (5) and (6), has been developed to overcome the disadvantage of the shorter working life of the cold-pressing urea-formaldehydes in warm weather, with the risk of the mixture setting in the spreader.

With the hot-press synthetic resins there is no call for this method because the working life of the adhesives is a long one, due to only a small quantity of a comparatively weak catalyst or hardener being necessary, the accelerating effect of the subsequent heating in the press being the main hardener.

The Separate Application Method

There are several different ways of carrying out the separate application process. One is to apply the urea-formaldehyde resin to each surface and the hardener separately on top, or, alternatively, the hardener can be the first coat and the urea-formaldehyde the second. Sometimes the same method is applied but the hardener and urea-formaldehyde resin are applied separately to one surface only and the other is left uncoated.

A more foolproof way and one which avoids contamination of the resin brush with the hardener or vice versa, as well as delaying the contact and reaction of the hardener on the resin until the joint is actually made, is to coat one surface with urea-formaldehyde resin and the other with hardener. With gap-filling cements, separate application may not prove so satisfactory, owing to inability of the hardener to travel through a thick mass of partly gelated cement.

103

The separate application method besides eliminating the drawback of short working life of a mixture and the use of retarders, such as ice jackets, also obviates the need for weighing and measuring and mixing ingredients, cuts out the waste through the cement setting in the pot or spreader, makes elaborate operation time-schedules unnecessary and renders possible faster setting by the use of stronger hardeners and higher room temperatures at the pressing stage.

Against these advantages it is claimed by the "ready mixed" school that with separate application there is risk of the hardener being omitted from the joint, that it is more convenient to have one pot of mixed cement in use than to have one of urea-formaldehyde resin and one of hardener and that, moreover, the mixture is easily applied to flat surface by a spreader, that mixed cement application is easier than separate on intricate work, particularly small pieces, that mixed cements are more familiar to the operators and, finally, that application of a mixture is usually only necessary to one surface, thus saving a complete operation.

There is truth in the contentions of both sides, but there is room for both methods, the advantages and disadvantages of which must be weighed up carefully by the reader as they apply to his particular manufacturing problems.

Application

The ready-mixed cold-press urea-formaldehyde resins are best applied by a mechanical spreader with rubber rollers where manufacture is of a suitable nature and the quantity of work justifies its use. Alternatively, a hand roller or a wooden spatula may be used. For application to small surfaces and angles a confectioner's icing-gun is a useful tool.

Different urea-formaldehyde brands vary greatly in their viscosity, and wood surfaces, in their turn, vary in evenness and porosity, all of which factors affect the decision as to whether it is necessary to coat both surfaces or one only; no hard-and-fast rule can be laid down about this.

After application and before pressing, it is necessary to allow the solvents to evaporate. To effect this, the coated surfaces should be left exposed for 5 to 10 minutes. Failure to allow this pause results in longer time being required under pressure.

In separate application, a paint-brush, stencil-brush, scrubbing-brush or wooden spatula should be used for spreading the urea-

formaldehyde resin, the variety of tool being selected according to the viscosity of the resin.

The fluid hardener applied separately is best spread with a soft brush or piece of felt attached to a brush handle. The same brush must not be used for the resin and the hardener.

Equipment

The urea-formaldehyde resins and hardeners, when mixed together, are strongly acid. Ready mixed urea-formaldehyde resins and hardeners can be used safely in containers of glass, porcelain, plastic, earthenware or waxed paper. Some but not all brands can also be used in containers of iron or tin, but these metals react on certain of the hardening acids. Bronze, copper or brass must never be used.

With separate application, the urea-formaldehyde resins may be used in containers of iron, tin, wood, glass, porcelain and earthenware and the hardener in containers of glass, earthenware or porcelain, but metal must not be used.

Containers must be perfectly clean and no trace of alkalis, such as soda or potash, alkaline soap or casein cement must come in contact with either the urea-formaldehyde resin, the hardener or the mixture of the two: any such contamination will seriously affect the working life and pressure time of the adhesive.

Containers should be cleaned in cold or tepid water before the cement has hardened. Hot water will speed the hardening process.

The Melamine-Formaldehyde Resins

The melamine-formaldehyde resins so far produced are all offered for sale in powder form for suspension in water before their application as adhesives.

Melamine is prepared from cyanamide, which in its turn is made from calcium carbide and nitrogen. The resins made by adding melamine to formaldehyde have been used largely as moulding powders. Their inclusion in the range of synthetic-resin adhesives is so recent that tests on their durability as adhesives are necessarily inadequate. It appears, though, that they resemble the urea-formaldehydes in their characteristics, bonding temperature requirements and general working technique.

Their initial resistance to moisture and high temperature is, however, considerably greater than that of the ureas and is

reported to be equal to that of the phenol-formaldehydes. In other words, they appear to combine low curing temperatures with high durability.

Fortified Urea Cements

In addition to the pure melamine-formaldehyde adhesives, what are known as fortified urea-resin cements have been developed. These are usually urea-resin mixtures fortified with phenolic compounds or melamine in order to give boil resistance. These mixtures are usually hot pressed at temperature ranges between those required for the phenols and the ureas.

Resorcinol Cements

Among the newly developed synthetic-resin adhesives which appear to have a useful future are the resorcinols, which are cold setting and gap filling and are used in conjunction with a hardener.

Adhesives of this type, made by the Pennsylvania Coal Products Co. under the brand name "Penacolite", are dark brown or dark wine coloured, viscous resin solutions of neutral pH, containing 52 per cent. to 70 per cent. solids, according to formula. They may be stored indefinitely, regardless of climate, as the base is not reactive by itself and must be mixed with the setting agent before it will harden. The resin pours readily but slowly at 80° F. (27° C.) and ladles easily at 0° F. (—18° C.).

One formula contains filler in the resin and is used in conjunction with a thin, slightly acid hardener, which also keeps indefinitely but must be stored at a temperature slightly above freezing. Another formula has an inert organic filler incorporated in a powder hardener.

Cold pressing

The actual cold-gluing operation is carried out in the manner already described for cold-setting resins. The makers advocate a thin application of the mixture to both the surfaces which are to be joined. Comparatively light pressure only is required, sufficient to produce a thin glue-line. Pressure must be maintained for about 6 hours, when the joints may be handled. Joints develop their full strength in from 1 to 5 days, according to the formula employed and the room temperature prevailing during curing.

Curing time can be accelerated considerably by the application of heat.

Properties

It is claimed that the resultant bonds are boilproof and are immune to climatic changes, moulds or fungi. Their high bond strength is attributed theoretically to the high polar characteristics of the resin base, also to its neutrality, which eliminates the deleterious action of acid upon the wood at the glue-line. The mixed glue does not impart any change in pH to distilled water.

A resorcinol adhesive will be on sale in this country in the near future.

THERMOPLASTICS

Of the thermoplastic synthetic-resin adhesives in actual use in woodwork, the vinyl-esters are best known, but there are a number of other combinations in an advanced stage of experiment. Of the vinyls, the polyvinyl butyrals, which were first developed for the bonding of the laminations of safety glass, are the ones most in use.

The thermoplastic resin adhesives appear to have a limited use for specialised purposes only.

It is extremely doubtful if they will ever prove popular in large-scale general production, owing to the fact that they remain plastic while hot and in consequence have to be cooled under pressure, thus retarding production by a slow pressing cycle.

This factor of continuous flow under heat, which in many processes is a serious disadvantage, is a great advantage in the building up of curved plywood by the flexible bag and autoclave processes, where attainment of the final shape may take considerable time (see Chapter 15). Another use for these adhesives is in experimental models which can be altered at will by the fresh application of heat above the normal curing range of 200° F. (93° C.) to 260° F. (127° C.).

Resistance tests on thermoplastics are incomplete as regards moisture and mould growths, but they are known to have a tendency to creep at temperatures around 160° F. (71° C.), and it seems that around this elevation there is some weakening of the bonds.

WOOD ADHESIVES

CHART 1.

Forms in which Phenol-Formaldehyde Adhesives are sold

Hot press					Low temperature
Film Adhesive	Ready-mixed syrup	Syrup to which liquid hardener is added at time of use	Powder for dissolving in water, alcohol or mixture of both	Powder for dissolving in water and mixing with similarly dissolved powdered blood albumin and hardener	Syrup to which hardener is added at time of use
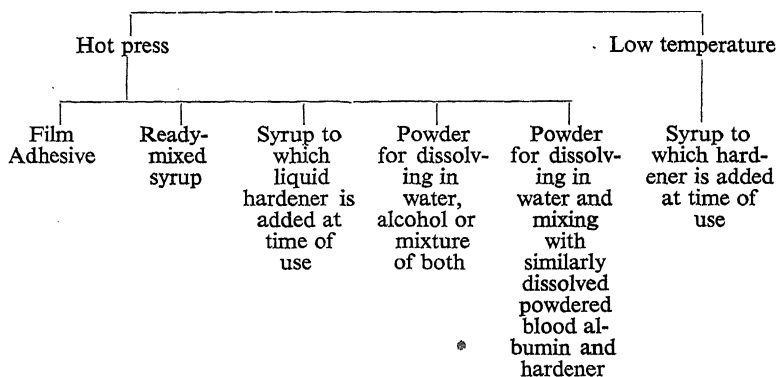
CHART 2.

Forms in which Hot-pressing Urea-Formaldehyde Adhesives are sold

Ready-mixed dry powder resin and hardener	Syrup to which liquid hardener is added at time of use	Syrup to which powdered hardener is added at time of use
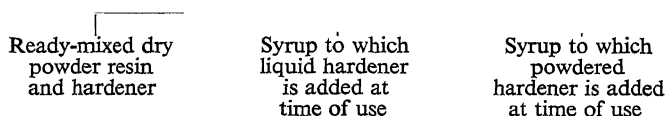
CHART 3.

Forms in which Cold-pressing Urea-Formaldehyde Adhesives are sold.

Ready-mixed application					Separate application
Ready-mixed dry powder resin and hardener	Dry powder for mixing with liquid hardener	Syrup to which liquid hardener is added at time of use	Syrup to which liquid hardener plus filler are added	Syrup for use in conjunction with liquid hardener	Dry powder for dissolving in water or spirit in conjunction with liquid hardener

Chapter 11
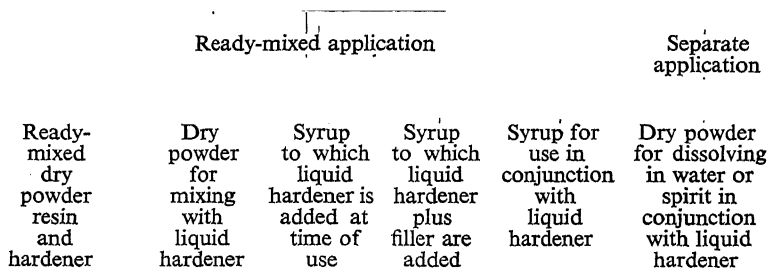
IMPREGNATION AND COMPRESSION

The Reasons for Impregnation

IMPREGNATION is one of the newest and most interesting of the forms of marriage of wood with synthetic resin.

One of the disadvantages of natural wood for many purposes has always been its tendency to change dimension and, to a lesser degree, shape, under varying atmospheric conditions. One of the purposes of plywood construction was to overcome this defect, and although it was a most valuable advance, it did not alter the hygroscopic nature of the wood, nor with the earlier adhesives was the bonding medium as durable as the wood itself under certain conditions of exposure. The advent of synthetic resins has opened up new possibilities and, though development is still in its infancy, numerous articles made from impregnated and compressed woods have, by reason of their superiority, ousted metal, which in its turn had been considered an improvement on wood.

In addition to its hygroscopic nature, natural wood for certain purposes has the further disadvantages of containing knots, splits, crooked grain, variable density and compression strength and in some of the less dense species such limited cohesion between the vertical fibres that the glue-lines in vertical jointed boards have shown themselves to be stronger than the material.

All these factors directed the minds of men to the possibility of improving wood's dimensional stability, lateral strength, toughness and surface hardness by filling the voids in the fibres with an inert and strongly adhesive substance such as a synthetic resin.

The difficulty of impregnating to a great depth and the fact that cutting the wood into veneers first gained the advantage of enabling visible defects to be cut out, led to the adoption of this method.

Uses of Impregnated Veneer Wood

Naturally, the material so created is not cheap, but it is well worth the cost for uses which demand high impact and tensile

strength combined with a weight which is low in comparison to most metals of equal strength. It is particularly valuable where the effects of fatigue are an important consideration, such as is the case in aircraft propeller and ventilation fan blades.

The alternative processes employed create mouldable woods of even density, largely stabilised against shrinkage and swelling, highly resistant to the effects of temperature changes, varying humidity and insect attack and of high insulation value and mechanical strength.

In addition to fan and propeller blades, the resultant material is already used for switch panels, gear wheels, pulleys, tools for pipe bending, moulds, jigs, mallet heads, reinforcing plates, etc.

It should be a logical step to develop this new product for many structural connections, such as those which occur in timber roof trusses, the members of which are invariably much larger in section than is justified by the weight which they have to carry, but which have to be made of large-section timbers owing to the impossibility of developing the full joint strength at the angles by bolting or nailing. A great improvement has been made in such connections recently by utilising glued and nailed plywood gussets, but their inclusion complicates construction and what is wanted is the equivalent of the steel ring connector which can be inserted into the faces of the two members which are to be joined together and which, unlike the metal ring connector, can be glued in place. Impregnated inserts would meet these requirements by replacing what is taken out of the wood at the junction by a material possessing the necessary strength and capable of being glued into position. Moreover, the cost of the impregnated veneer inserts would be much more than compensated for by the saving of timber in the structural members.

In general "Impreg" and "Compreg" cannot be bent, nailed, screwed or sawn with woodworking tools, but they are easily worked by methods associated with metals or plastics.

Different Classes of Impregnated Veneer Wood and their Methods of Manufacture

There are several different processes of impregnation, but they form two main varieties of products; those which are impregnated but not compressed are usually known as "impreg" products and those which are impregnated and compressed under heat are known as "compreg".

"Tego Gluefilm-bonded improved wood," sometimes known as "Tegowood", "Jicwood" and "Hydulignum", are speciality forms of "compreg" with certain unique features which are described later. Other names for "compreg" products are "improved wood" and "high-density plywood".

"Impreg"   ·

Ordinary "impreg" is carried out either by immersion or by spreading the veneers with a liquid resin. The immersion process is described under "compreg", the difference between "impreg" and "compreg" merely being in the bonding pressure, which in the case of "impreg" is only sufficient to compress the veneers into a perfect bond with each other. In the case of impregnation by spreading, the veneers are coated with a suitable hot bonding resin, applied by means of a mechanical spreader. They are then dried and hot pressed. The heat and time in press are controlled by the same factors as those which operate in the hot pressing of resin-bonded plywood. With sufficient heat, pressure and time in press, there is a pick-up of approximately 20 per cent. on $\frac{1}{16}$ in. birch veneer.

"Impreg" Sandwich Board

A new application of "impreg" which is finding favour is in the treatment of some of the layers of a board only by impregnation and then bonding them to ordinary plywood or other suitable material. By this means boards can be built up with hard skins and soft cores or, conversely, with soft skins and hard cores. They are naturally much lighter in weight than all "compreg" boards of equal thickness and the boards with hard skins are particularly valuable where conditions of abrasion are likely to be met, as on the outside of hulls of boats, whilst the soft-skinned, hard cored variety gives strength with better fixing on the outside faces for additional glued or screwed attachments.

"Compreg"

The wood selected is first cut into thin veneers and then impregnated with a phenol-formaldehyde resin solution by immersion at atmospheric pressure or under a vacuum pressure cycle.

In the atmospheric pressure process the veneers are immersed in the resin for a length of time dependent on the thickness of the

veneer, its moisture content and the resin content required. Veneer with a moisture content of under 6 per cent. will not absorb the resin satisfactorily. Veneer with more than double this moisture content may be used for many purposes and will absorb the resin faster. Birch veneer of 18 gauge, containing 10 per cent. moisture, will take up approximately 25 per cent. of resin (calculated as dry resin) in twelve hours.

In the vacuum pressure process, the veneers are placed in an impregnation chamber where a vacuum of at least 20 ins. is applied for a half hour. Resin sufficient to immerse the veneers is then sucked into the voids of the wood structure, the vacuum released and a pressure of 50–100 lbs. per sq. in. applied for approximately one hour. The impregnated veneers are then drained, wiped free of excessive resin and dried, usually in a hot-air circulating chamber, before being reconstituted and cured by compression and heat.

Arranging the veneers

The veneers, whether for "impreg" or "compreg", are arranged for reconstituting according to the particular requirement of the finished article. When strength is only important in one direction, all veneers run in the same direction; where equal strength both ways or some particular stress has to be taken up by the completed moulding, alternate ones may be at right angles or at some intermediate angle to each other.

The physical properties of the completed moulding will vary not only according to the direction of grain of the veneer but also according to its variety, thickness and degree of compression. This ability to vary pressure over a wide range is important, since not only does it allow for control of density of the moulding, but also, by arranging extra thicknesses of the veneers at a certain spot in the "build up" before pressing, one part of a moulding can be made more dense than another. Aircraft propeller blades with differential density are built up in this manner. Pressure is commonly applied over a range varying from 250 lbs. ("impreg") to 1,500–2,000 lbs. ("compreg") per sq. in.

The Resin

The most commonly used variety is a hot press, highly penetrative phenol-formaldehyde resin, such as Bakelite Resin R568, which is soluble in water or a mixture of water with a small

quantity of methylated spirit. An impregnating phenolic resin of this nature also acts as the adhesive between the veneer layers, but in some processes a supplementary adhesive is used.

To avoid warping and other defects, it is considered advisable to place the prepared assembly under pressure before applying the heat, which should be in the neighbourhood of 300° F. (149° C.) at the adhesive line furthest from the heated platen, and pressure should be maintained until the temperature has dropped below 150° F. (66° C.).

Time required under heated pressure will vary according to the thickness of the product and may be anything from 20 to 40 minutes. It is important that full pressure be maintained continuously during the whole of this period, which is the compression stage. The specific gravity of the finished product will be about 1·35.

When more than 20 per cent. resin pick-up is attained, the increase in the quality of dimensional stability under immersion or boiling tests tends to involve the sacrifice of wood resiliency and impact resistance; in other words, the product is becoming fibre-reinforced resin rather than resin-toughened wood. This point requires careful consideration in deciding the optimum resin pick-up for a specific purpose.

Hydulignum

Some manufacturers require the production of a form of compressed wood which is not only pressed from top to bottom of the pack, but also from side to side, thus ensuring approximately equal shear values in both directions, longitudinal tranverse and longitudinal normal to the grain.

The unique Hydulignum process developed by Hordern-Richmond, Ltd., meets these conditions by using a thermoplastic resin, Formvar (polyvinyl acetal). The use of thermosetting resins is excluded, since a second pressing cycle under the same degree of heat is required. Consequently, a pack of veneers which has already been consolidated to a density of 0·96 can now, by side pressing, be raised to a density of over 1·3. By this process, since impregnation of the wood is very slight, the fibrous structure of the wood is retained, which gives higher resistance to flexing and shock and gives a board of high specific strength, greater than that of structural steel. Boards of uniform low, uniform high and variable density can be produced.

Tego Gluefilm-bonded Improved Wood

This is the simplest form of "compreg" to construct. The extreme thinness of the veneers necessitated by the process and the consequent multiplicity of film and veneer layers results in increased cost of materials, but this is compensated by the saving of operations effected by the use of Gluefilm. The veneers must not be cut to a thickness of more than $\frac{1}{28}$ in., and the thinner they are than this, the greater will be the strength of the finished product. After drying to 10 per cent. moisture content they are interleaved with Tego Gluefilm as described in Chapter 10.

The pressure required to make Tego Gluefilm-bonded improved wood is 1,500 to 2,500 lbs. per sq. in. This should be maintained for 20 minutes at 295° F. (146° C.) for the glue-line furthest from the heated platen, and under these conditions the finished product will have a specific gravity of 1·35. In order to reduce the risk of warping, Tego Gluefilm-bonded improved wood veneer and film assemblies are usually placed in the press under full pressure before application of heat and they are left under pressure until the heat has been reduced below 150° F. (66° C.).

Tego Gluefilm-bonded improved wood process lends itself to the easy building up of products with differential density.

The resin pick-up of Tego Gluefilm-bonded improved wood, made under the conditions already described, is lower than that of some other forms of "compreg", being 6 per cent. for $\frac{1}{28}$-in., 9 per cent. for $\frac{1}{36}$-in., 11 per cent. for $\frac{1}{45}$-in. and 18 per cent. for $\frac{1}{80}$-in. birch veneers. Because of this lower resin pick-up, dimensional stability, particularly with the thicker veneers, is also somewhat lower under cold immersion and boiling tests. The importance of this can be easily overestimated, for in the majority of cases conditions of total immersion or boiling do not occur and even where they do, some slight expansion may be an advantage, such as in boat-building.

What is important is that this low resin pick-up preserves for Tego Gluefilm-bonded improved wood a high degree of normal wood resiliency and impact resistance, which is sacrificed in other forms of "compreg" if the resin pick-up is carried too far.

Jicwood

In the manufacture of Jicwood considerably thicker veneers are used than in the two other specialities already described.

In Jicwood, liquid spirit-soluble resins are used, and veneer of a thickness of $\frac{1}{16}$-in. is normally used.

The veneers, to which the resin has been applied by the normal spreading methods, are kilned before and after the application of resin, first to reduce the moisture content to a suitable level and secondly to remove the spirit from the resin solution. This having been done, the veneers are packed in the press and the pressure which is employed is sufficient to compress the veneers as far as it is possible to do so.

Under this pressure the resin flows sufficiently to be forced into the various fibres of the timber. This method produces a final product which is admirably suited to the purpose to which it is mainly put, namely, the root ends of airscrew blades.

Physical Properties

Owing to the varying methods of construction, thickness of veneers, varieties of wood, differences in resin pick-up and degrees of compression, there is considerable difference in the physical properties within the "compreg" and "impreg" groups. The figures set out below cover the general range of "compreg" material, when made from birch veneers, not more than $\frac{1}{16}$-in. thick and assembled with the veneers parallel to each other and pressed within the range of 1,500–2,500 lbs. per sq. in. giving a specific gravity of 1·3–1·38 (approximately the same as lignum vitæ and boxwood).

Tensile Strength, lbs. per sq. in.	Compression Strength, lbs. per sq. in.	Modulus of rupture in bending	Modulus of elasticity in bending
34,000 to 45,000	20,000 to 25,000	36,000 to 48,000	3,000,000 to 4,400,000

Arboneeld

A chapter on impregnation would not be complete without a reference to a new process of impregnation for solid timber—that is, in the board. Though still in an experimental stage, it shows evidence of a quite revolutionary character. It is claimed that this process can convert "softwoods" into the equivalent of hardwoods, so hard that they require steel-cutting tools. The significance of this will be readily appreciated, for such a claim, if substantiated, means that quick-growing conifers could be made to do the constructional work of hardwoods and the increased cost of natural hardwoods, largely due to their much

greater maturity cycle, would be overcome where strength, not appearance, was the main consideration.

The process is that on which the Du Pont de Nemours Co. in the United States is experimenting and consists of treating wood with a solution of methylolurea, designated "Arboneeld". The wood is first subjected to a vacuum period; sufficient solution is then introduced to cover the wood and allow for the volume of solution which will be absorbed and finally, air pressure is applied. The natural acids in the wood convert the methylolurea into resin and a hard, insoluble permanent resin is formed within the wood structure.

It is held that the treated wood is more dimensionally stable under varying conditions of humidity, does not show grain rising, is markedly hardened, can be highly polished, is stiffer, more durable and denser, has increased wearing strength and has a much higher compressive strength as well as increased tension, particularly across the grain. The wood may be compressed to any desired specific gravity up to about 1·4. The flame resistance is improved and it is said to be more resistant to the action of most chemical agents, to fungi, rot and pest infestation. Wood dye stains may be introduced with the impregnating chemicals to impart colour.

When the veneers are sufficiently impregnated and dried, it is claimed that they become self-bonding under the heat and pressure of the hot laminating presses and no additional adhesive is required to form plywoods.

Sapwoods are said to impregnate more easily than heartwoods and the heartwoods of some species to be particularly difficult to treat.

This process, therefore, appears to hold promise of a wealth of industrial applications and its further development merits careful watching.

Staypak

Since the present chapter was written, details have been received of a new type of heat-stabilised compressed wood which has been developed by the U.S. Forest Products Research Laboratory under the name of "Staypak".

By kind permission of the U.S. Forest Products Laboratory, their report (slightly abridged) on this new type of compressed wood is given in the Appendix to this chapter.

Appendix to Chapter 11

U.S. FOREST PRODUCTS LABORATORY'S REPORT
(slightly abridged) on "HEAT-STABILISED COMPRESSED WOOD (STAYPAK)", [1], [2]

by R. M. Seborg, M. A. Millett and A. J. Stamm

Introduction

By compressing wood under conditions that cause sufficient flow of the lignin (the cementing materials between fibres) to relieve the internal stresses resulting from the compression, it has been found possible to eliminate the springback tendency encountered in the usual densified wood. When wood is compressed at higher temperatures and moisture contents than are normally used, it does not, when swollen, tend to recover the original uncompressed dimensions. Wood so processed has been named "Staypak" by the Forest Products Laboratory.

Staypak has distinct advantages over both the normal densified wood,[3] or "improved wood" as it is sometimes called, and compreg.[4] Whereas densified wood tends to lose its compression to a marked degree under conditions that cause swelling, staypak, although it will swell appreciably, will return to practically the original compressed thickness on drying to the original moisture content.

The behaviour of compreg with respect to recovery of its original dimensions varies depending upon the conditions under which it was manufactured. Because of the stabilising influence of the resin, it is possible to make compreg with negligible springback tendencies. The advantages of staypak over all compreg, however, lie in its strength characteristics. Although the shear strength parallel to the grain and in a plane perpendicular to the

---

[1] "Staypak" is heat-stabilised, compressed wood that has been heated, during the pressing process, under conditions such that the compression is not lost when the wood is subsequently swollen. Although it will swell appreciably, it will return to practically the original compressed thickness on drying to the original moisture content. It is thus wood that "stays compressed".

[2] This report is one of a series of progress reports which was prepared by the Forest Products Laboratory to further the nation's war effort. Results here reported are preliminary and may be revised as additional data become available.

[3] Densified wood is normal untreated wood that has been compressed under conditions that do not cause flow of the lignin cementing material. It has been made from solid wood and also from veneer preferably assembled with a synthetic-resin glue.

[4] Compreg is resin-treated, compressed wood which is stabilised in the compressed form by the resin.

direction of compression of the wood is appreciably lower for staypak than for compreg, the impact strength is about double, and the tensile and bending strengths are approximately 25 per cent. more than those of compreg.

The manufacturing conditions under which staypak with the optimum dimensional stability can be made will be discussed, together with the characteristics of the material thereby obtained, the species and form of wood that may be used and the possible uses of the final product.

Effect of Moisture-Content–temperature–time Variables in making Staypak

A series of tests were made at the Forest Products Laboratory on yellow poplar veneer to determine the best combinations of moisture content, temperature and time of pressing to obtain panels with optimum stability. Yellow poplar was used because it is compressed to a greater extent in making a high-specific-gravity product than are denser hardwoods, and consequently its tendency to recover from compression should be greater. The choice of yellow poplar, therefore, should accentuate differences in the product made under different conditions. Compressed parallel-laminated panels $13 \cdot 5 \times 9 \cdot 5$ in. $\times$ about $0 \cdot 6$ in. were made from 21 plies of $\frac{1}{16}$-in. veneer glued with Bakelite resin XC7381. All the panels were compressed at 2,000 lbs. per sq. in. and at temperatures ranging from 300° to 360° F,[1] using veneer conditioned at 30, 50, and 65 per cent. relative humidity (moisture contents of 6, 9, and 12 per cent. respectively). The time that the centre of the panels was held at the heating temperature was either 5 or 30 minutes.

Figure 1 shows the relationship between the specific gravity to which the wood is compressed and the moisture content, temperature and time of heating. The wood conditioned at 65 per cent. relative humidity compresses more readily than the wood conditioned at 30 per cent. relative humidity, especially at the lower temperatures and shorter times, as a result of the plasticising action of the additional moisture. An increase in temperature for the wood conditioned at the higher relative humidity has less effect upon increasing the compressibility than the same temperature increase for wood conditioned at the lower relative humidity. The wood conditioned at the higher relative

[1] 149–182° C.

humidity is sufficiently plasticised even at the lower temperatures
to be almost completely compressed. An increase in the time has
a similar effect. Under temperature conditions which do not
cause optimum flow, increasing the time makes possible a greater
extent of flow.
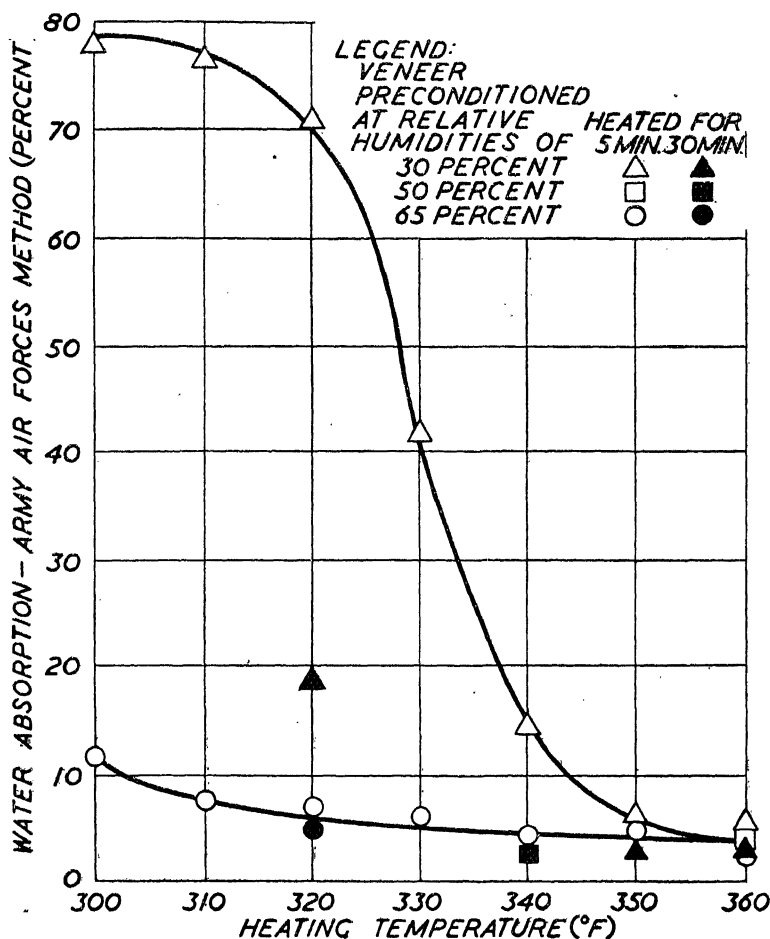
FIG. 1—EFFECT OF THE RELATIVE HUMIDITY AT WHICH THE VENEER WAS CON-
DITIONED, THE FINAL HEATING TEMPERATURE AND THE TIME UPON THE SPECIFIC
GRAVITY OF PARALLEL-LAMINATED YELLOW POPLAR STAYPAK PRESSED AT 2,000
LBS. PER SQ. IN.

Fig. 2 shows that the water absorption, determined on 3 × 1
× ⅜-in. specimens (1 in. in the fibre direction) according to
the Army Air Forces method (weight increase after 24 hours'
119

immersion), is much less for the specimens made from veneer conditioned at 65 per cent. relative humidity than for specimens made from veneer conditioned at 30 per cent. relative humidity, except at the highest temperatures. Increasing the time of heating for the less moisture-resistant specimens also greatly decreases the water absorption.
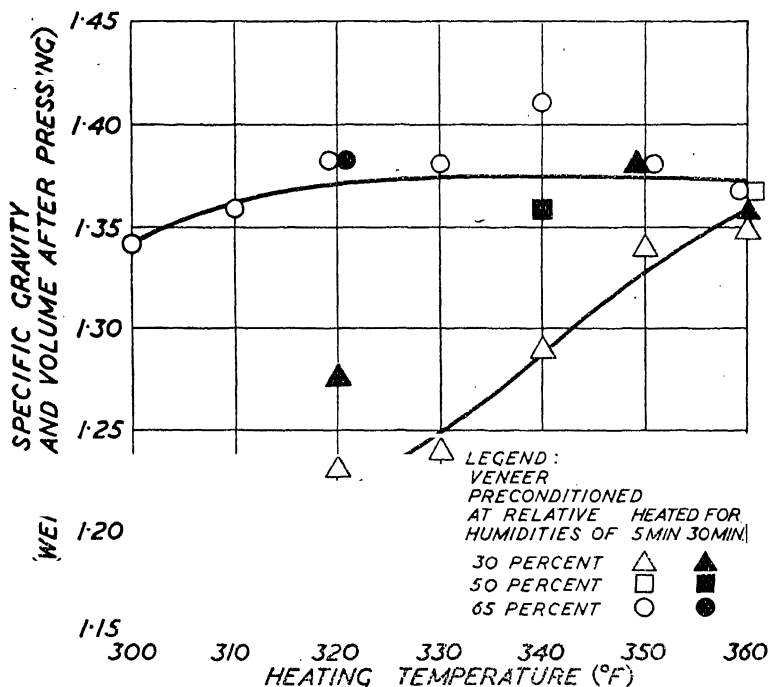
FIG. 2—EFFECT OF RELATIVE HUMIDITY AT WHICH THE VENEER WAS CONDITIONED, THE FINAL HEATING TEMPERATURE, AND THE TIME UPON THE WATER ABSORPTION OF PARALLEL-LAMINATED YELLOW POPLAR STAYPAK PRESSED AT 2,000 LBS. PER SQ. IN.

A similar decrease in the equilibrium swelling and recovery from compression and in the permanent recovery from compression, after drying, occurs with increasing moisture content and temperature and time of heating. The equilibrium swelling under conditions such that the recovery is small is about 25 per cent. The reason why this swelling is considerably greater than the swelling of normal wood is that the wood still retains its normal swelling tendency, but because the volume has been reduced to about one-third of normal, the swelling per unit of reduced volume is about trebled. This increased swelling is not so serious as may

120

be thought, for swelling of sizable pieces of highly compressed wood in the absence of a tendency to recover to the uncompressed dimensions, is extremely slow. Staypak swells so slowly in sizable pieces that dimension changes and warping are negligible for most uses. The surface fibres of staypak, however, respond to humidity changes readily, and, as a result, staypak weathers on the surface like normal wood, assuming a greyish colour with many fine hair-line checks, when exposed to direct sunlight and moisture changes for long periods of time without a surface finish.

The wood is appreciably darkened in colour under the stabilisation conditions used in making staypak. The darkening is, undoubtedly, associated with some chemical change of the lignin that occurs under flow conditions. The colour change is so sensitive that a series of specimens of a single species arranged in the order of increasing darkness are in the order of increasing stability.

Table 1 gives the properties of yellow poplar staypak made from veneer containing 9 per cent. moisture (in equilibrium with 50 per cent. relative humidity) that was pressed at 2,000 lbs. per sq. in. at a temperature of 340° F.[1] for different periods of time. The data indicate a progressive improvement in the stability as the heating time is increased.

TABLE 1. EFFECT OF VARIATIONS IN THE STABILISATION TIME OF YELLOW POPLAR STAYPAK UPON ITS PROPERTIES

Centre of Wood held at Stabilisation Temperature, minutes	Specific Gravity	Water Absorption, per cent.	Equilibrium Swelling and Recovery, per cent.	Permanent Recovery, per cent.	Notched Toughness, in.-lbs.
10	1·35	5·8	47·7	19·8	135
20	1·36	4·3	38·0	9·7	141
30	1·36	3·5	33·2	6·4	130
60	1·37	3·2	26·8	2·5	125

Attempts to plasticise further the Lignin

Attempts were made to plasticise further the lignin of the wood at the time of pressing by using yellow poplar veneer previously treated with each of the following chemicals: 10 per cent. of urea, hexamethylene tetramine, and formaldehyde, followed by

[1] 171° C.

conditioning at 30 per cent. relative humidity and pressing at 350° F.[1] for 15 minutes. The compression was not increased nor were the properties improved. Due to the hygroscopic properties of urea, it had an adverse effect upon the stability. Treating veneer containing 9 per cent. moisture with pyridine, an excellent swelling agent for lignin, also failed to give the expected increase in plasticity under stabilising conditions. Attempts to make staypak with glycerine replacing the water plasticiser gave an inferior product.

Veneer treated with a diacetone-alcohol solution of lignin so as to increase the lignin content of the wood by about 50 per cent. aided slightly in reducing the required compression pressure.

The resulting staypak was darker in colour and was more glossy than normal. The decrease in the required pressing pressure, however, was not sufficiently great to justify the treatment. It thus appears that the use of plasticisers other than water are not practical.

Manufacturing Conditions

Stabilisation Temperature

Although the data obtained indicate that the use of a temperature of 350–360° F.[2] would permit more rapid manufacture of staypak, experiments in making large panels of commercial size (54 × 14 × $\frac{5}{8}$ to $1\frac{1}{4}$ in.) indicate that these temperatures are too high when used on large pieces because they cause blistering and checking. This degrade in large, thick panels is due to the necessarily increased total time that the material must be in the press in order to get the heat to the centre of the panels. The temperature range of 330–345° F.[3] has proved to be the most satisfactory for making large panels of staypak that are check- and blister-free, from birch and maple, using the lower temperature for the thicker material.

Moisture Content

It is preferable to avoid moisture contents over 15 per cent.; it is still better to use veneer at 6–10 per cent. moisture content.

Excessive moisture (a) requires the use of excessive heat energy in raising the temperature of the wood to the required point; (b) increases the chances of the panel blistering or checking upon the

---

[1] 177° C.   [2] 177–182° C.   [3] 166–174° C.

release of the pressure; (c) increases the difficulty in properly bonding the plies together; and (d) gives a finished product that tends to lose moisture and shrink with time. As a moisture content of 8 per cent. may be considered to be a good average service equilibrium value for most parts of the United States, all the developmental work on large panels of staypak has been confined to material conditioned at 30–50 per cent. relative humidity to a moisture content of 6–9 per cent. The wood has invariably been conditioned both before and after application of the bonding resin. It is believed, however, that the conditioning prior to application of the bonding resin can be omitted when the veneer is originally at approximately the desired moisture content.

Subsequent exposure of the specimens to prolonged low relative humidity, as in heated, unhumidified buildings during the winter months and heating in an unhumidified oven at 140° F. [1] for 24 hours, showed that staypak made up at moisture contents appreciably above 6 per cent. tends to end-check to some extent. Staypak that is to be used in heated buildings or exposed to the direct rays of the sun under low relative humidity conditions should, hence, be made from wood conditioned to 6 per cent. moisture rather than the higher, more suitable values for rapid stabilisation.

Moisture Loss in Pressing

One of the chief difficulties encountered in making staypak is the loss of moisture from the end grain of the veneer during pressing. If the final pressing temperature is attained before the wood is highly compressed, sufficient moisture is lost from the ends to prevent them from being properly stabilised. Insufficient stabilisation at the ends of the panels can be detected by the eye, for then the ends are not as dark in colour as they are when properly stabilised. Under conditions such that an appreciable amount of moisture is lost from the end grain, an excessive part of the panel must be trimmed off before use. To avoid this loss of material and to make the process practical, a number of ways of avoiding end-grain moisture loss were developed. The most effective of these is to load the press cold, apply the full compression pressure, and then heat to about 220° F.[2] at the centre of the panel with the platens at about 250° F.[3] The wood is compressed very slightly at first, but as the temperature rises to 220° F.[2] the compression

[1] 60° C.   [2] 104° C.   [3] 121° C.

becomes virtually complete. At this temperature the vapour pressure of water is only about 3 lbs. per sq. in. in contrast to the vapour pressure of 120 lbs. per sq. in. at 350° F.[1] The tendency for moisture to be driven out of the wood under pressure up to this stage is therefore relatively small. The compression that occurs at 220° F.[2] however, is sufficiently complete to bottle the contained moisture within the wood. Subsequent heating of the wood to 330–350° F.[3], after the compression at 220° F.[2] is fairly complete, causes the desired stabilisation and completion of compression with a much smaller moisture loss than occurs when the wood is immediately raised to the higher temperature.

Another aid to the stabilisation of the wood under heat and pressure that tends to reduce moisture loss from the end grain of the surface plies when veneer is used, is to cut the two face plies about ¼ in. shorter than the other plies. The assembly of plies is laid up for pressing with the face plies ⅛ in. shorter at each end than the rest of the assembly. This causes the second plies to spread over the end grain of the face plies when the assembly is compressed and, as a result, seal off the end-grain capillaries of the face plies. Because of the greater heating and higher average temperature of the face plies during the compression stage of the process, the face plies are more subject to moisture loss than the inside plies. It is desirable to follow this technique in combination with the first method of avoiding moisture loss in making the stabilised, compressed product from veneer.

The end-grain moisture loss between the faces of the wood and the press platens or cauls may be minimised by a method that is effective for both veneer and solid wood. A strip of thermosetting glue about ½ in. wide is applied to the faces along the end grain. When the veneer assembly or the boards are pressed, this glue sets sufficiently to seal any capillaries formed between the wood and the press platens or cauls, thus preventing capillaries from carrying away water vapour.

A fourth method of minimising moisture loss consists in dipping the end grain of the veneer sheets that have been spread with bonding resin ½ to 1 in. deep into a treating resinoid, such as one of those used for making compreg, for about 10 minutes. Sufficient absorption of resin occurs in the coarse capillary structure at the ends of the veneer sheets to seal the moisture

[1] 177° C. [2] 104° C. [3] 166–177° C.

in the wood as a result of the curing of the resin at the time of pressing. When the veneer is similarly dipped prior to applying the bonding resin, so much resin is taken up, with resultant swelling, that the panels tend to spread excessively at the ends when pressed as a result of the greater thickness and plasticity of the ends.

The practice of end dipping after the spreading of the bonding resin, followed by reconditioning to 6–9 per cent. moisture content and then pressing under the two-step temperature rise conditions has been adopted as standard practice in making staypak. Under these conditions the amount of unstabilised wood that has to be trimmed off the ends is a minimum.

Pressure

The pressure of 2,000 lbs. per sq. in. used in making yellow poplar staypak has been shown to be greater than necessary to make staypak under most stabilisation conditions.

Excessive pressure tends to cause a spreading of the panels that may reduce the shear strength at right angles to the direction of compression. Pressures of 1,400 and 1,600 lbs. per sq. in. appear to be adequate to give sufficient compression of yellow birch and sugar maple respectively.

When too low pressures are used, the product is far less dimensionally stable than when it is highly compressed. For this reason it is recommended that staypak always be compressed to a specific gravity of at least 1·30.

Due to the thermoplastic nature of the lignin, it is important that the panels be cooled to somewhat below the boiling-point of water while under the full pressing pressure before they are withdrawn.

Side Restraint

When staypak is made from parallel-laminated veneer or from solid wood in thicknesses of ½ in. or more there is a tendency for the wood to spread in the across-the-fibre direction under pressure. When no side restraint is applied, the spreading of the panels is sufficient to reduce appreciably the specific gravity of the product near the edges. This same difficulty is encountered in the manufacture of compreg. Some form of side restraint should be used in making parallel-laminated staypak. This restraint can be

provided by using a mould with stiff, sturdy sides, capable of withstanding a side thrust of at least 500 lbs. per sq. in.

When a relatively few panels of each size and thickness are to be made, it will not pay to have a mould made for this purpose. Blocks of wood or packs of veneer strips approximately equal in thickness to the original wood, placed snugly along the fibre-direction edges of the panel assembly will furnish the necessary restraint when pressure is applied. It is necessary that the veneer packs or blocks have their end grain against the panel, for then the restraining material shows no tendency to spread in the same direction as the panels. Blocks need not be placed continuously along the edge of the panel to be pressed. Blocks 2 to 3 in. long in the fibre direction of the panel may be spaced 2 to 3 in. apart, thus applying an intermittent restraint along half the length of the panel. There is a slight spreading between restraining blocks, but this is not sufficient to reduce appreciably the specific gravity of the product along the edges of the panel.

Time of Pressing

It has been shown that the stabilisation time will vary with the stabilisation temperature and the moisture content of the wood. The time that the centre of the wood need be held at the optimum temperature will also vary with the thickness of the wood. Thick material, such as $1\frac{1}{4}$-in. panels, will require a longer time to heat and to cool than $\frac{7}{8}$-in. panels, thus the centre of the thicker material need not be held quite so long at the optimum temperature. Table 3 gives the time required to make 53 × 14-in. panels of birch staypak in two thicknesses from veneer conditioned at 50 per cent. relative humidity.

TABLE 2. TIME FOR MAKING 53 × 14-IN. PANELS OF YELLOW BIRCH STAYPAK OF TWO DIFFERENT THICKNESSES FROM VENEER CONDITIONED AT 50 PER CENT. RELATIVE HUMIDITY.

Operations	Time, minutes	
	· in. Thick	$1\frac{1}{4}$ in. Thick
Heating platens	15	15
Heating centre of wood at 335° F.[1]	30	70
Holding temperature at 335° F.[1]	15	10
Cooling at 85° F.[2]	25	45
Total	85	140

[1] 168° C.   29° C.

The time required for heating and cooling the $\frac{3}{4}$-in. staypak should be half that for the $1\frac{1}{4}$-in. staypak on the basis of the time varying as the square of the thickness. This was found to be approximately true.

Type and Species of Wood

The thickness of the veneer used has a negligible effect upon the properties of the staypak. It is preferable from a manufacturing standpoint to use $\frac{1}{8}$-in. veneer or even thicker when parallel-laminated products are sought because of the saving in handling costs and in glue. Staypak has been sucessfully made from solid wood. This material, which contains no synthetic resin, is comparable in properties with the parallel-laminated staypak made from veneer, showing that glue-lines of synthetic resin do not improve the properties of the product.

Tests were made to determine if cross-banded staypak can be made from preformed plywood. Matched panels of preformed plywood and plywood made up at the time of compressing and stabilising, using a hot-setting phenolic glue, gave similar shear values in the plane of the plies, indicating that no injury to the preformed synthetic-resin glue-lines occurs under the conditions for making staypak. Similar panels made with casein glue gave poor shear strengths in the preformed glue-lines, indicating that they will not stand the conditions for making staypak. Casein glue can, however, be used in making staypak from veneer when the glue is set at the time of compressing and stabilising the wood.

Staypak can be made from a variety of species. It has been successfully made from veneer and solid wood of yellow birch, sugar maple, black walnut, and Sitka spruce, from veneer of yellow poplar, cottonwood, sweetgum, and Douglas fir, and from solid hickory, white oak, red alder, and white fir. Difficulty in stabilising the product was encountered with solid Douglas fir and ponderosa pine. This appeared to be due to the natural resins of the wood. Contrary to the findings with other species, the stabilisation was best at the ends of the specimens, presumably because the natural resins of the wood were squeezed out of the end grain. The fact that Douglas fir veneer made satisfactory staypak while the solid wood did not was presumably due to the high temperature drying of the veneer that caused volatilisation of part of the natural resins and fixing of the remaining resins, thus reducing the interferences of natural resins with stabilisation.

127

The only limitation in the choice of species for making staypak, according to the present procedure, seems to be avoiding the use of resinous, pitchy solid wood.

It is surprising that oak, with its high acidity, was suitable for making staypak. Evidently the tendency for hydrolysis to take place under the manufacturing conditions is not great.

When staypak is made of solid wood it should be made from flat-grain stock free from knots that are the full thickness of the wood. Summerwood will not compress to as great an extent as will springwood because of its high specific gravity. The summerwood rings will not compress to the degree that the wood as a whole will compress, and hence they will buckle and distort badly when quarter-sawn boards are used, giving an unhomogeneous product. Knots have a considerably higher specific gravity than the normal wood and will take most of the load in compressing due to their lower compressibility. The knots will therefore tend to spread and crack the board. They are further liable to overstress the press.

Strength Properties

The strength properties of staypak are considerably higher than those of the normal wood from which it is made, the strength increases being about in direct proportion to the compression. The tensile strength, modulus of rupture, and modulus of elasticity in bending are significantly greater than for compreg of the same specific gravity. This is due to the fact that resin contributes to the weight and volume but not to these particular strength properties. Compreg, however, has a slightly higher compressive strength than staypak, due to the fact that resin does contribute to this property to a greater extent than to the increase in weight and volume.

The chief advantage of staypak over adequately stabilised compreg is its superior impact strength. Staypak, in general, has twice the Izod values of compreg. The break across the specimen is fibrous in contrast to the granular break of compreg, indicating a lack of embrittlement in the staypak.

Gluing Staypak

Preliminary gluing tests indicate that staypak can be glued to itself or to normal wood more readily than can compreg.

128

Good joints were obtained with various hot- and cold-setting urea and phenolic glues.

Although good glue joints giving 100 per cent. wood failure can be obtained with small blocks that have not been surfaced, large thick panels are seldom sufficiently flat to give very good glue joints. A means of making the surfaces plane for gluing by scraping them with a special knife has been developed.

Attack by Termites

Preliminary termite exposure tests of birch staypak under severe outdoors conditions for 6 months indicate that staypak shows little if any resistance to attack and is considerably inferior to compreg in this respect.

Potential Uses of Staypak

Staypak should have many uses, for it has an Izod impact strength about twice that of stabilised compreg and appreciably greater than that of unstabilised compreg. Consequently it should be less susceptible to concentration of stresses. It has a greater stability than most of the high-impact-strength compregs, and it is potentially cheaper to produce. Propeller blanks are now being prepared of staypak at the Forest Products Laboratory and test airplane propellers will be carved to determine its suitability to replace compreg. Because staypak is less notch sensitive than compreg it should be more suitable for spar plates and various fittings. It should also be suitable for tool handles, mallet heads, pulleys, silent gears, and various tooling jigs and dies. Because of its greater swelling than that of compreg, staypak will not be so suitable for water-lubricated bearings or other underwater uses.

Summary

Solid, flat-sawn, non-resinous wood and veneer, spread with glue and assembled in parallel-laminated or cross-banded form, can be compressed to a high specific gravity product that does not tend to spring back under moisture-absorbing conditions when it is pressed under conditions that cause some flow of the lignin. The conditions for making this material, called "staypak", and its chief physical properties have been determined. It is shown to have several strength properties superior to compreg, most notable of which is its greater impact strength. Although it is not as dimensionally stable as compreg, it is sufficiently stable for many uses.

9

Chapter 12

EDGE-JOINTING OF VENEERS

A great advance was made in veneering and plywood manufacturing when, round about 1918, it became possible for the first time to obtain "invisible" veneer joints straight off a saw without subsequent shooting by plane or planer. This was achieved by veneer jointing or trimming machines in which a very fine circular saw moves along an overhead steel track, trimming the edges of a pack of veneers tightly clamped down to a steel table.

About the same time an ingenious veneer tape joining machine was invented, in which a pair of veneers trimmed by the above mentioned machine were inserted side by side and gripped by overhead rollers so arranged that they pressed the veneers on to two gradually converging lines of caterpillar tracks. At the point where the edges of the two veneers came tightly together they passed under a roll of gum tape, which had in turn passed over a moistening wheel operating in an electrically heated moistening tank, so designed that it had brought the tape to the right degree of tackiness for consolidating the joint under a pressure roller placed forward of the tank.

The system had the disadvantage of subsequent trouble, expense and sometimes damage both to sanding machines and veneer which was entailed in the removal of the tape. To overcome this, the tapeless edge-to-edge veneer joining machine was invented and this eliminated the taping operation entirely.

In the new process, the edges of the clamped pack of veneers are coated with adhesive while still held in the clamp of the trimming machine and the veneers are then removed and, if hide glue has been used, they are allowed to dry out.

They are subsequently fed in pairs on to the caterpillar tracks of the tapeless joining machine table, shown in Plate 4, which is fitted with two overhead moistening wheels followed by a series of pressure rollers, so arranged that they "toe in" or bring the two veneers tightly together without overlapping. The caterpillar tracks in the table and the upper rollers are both

130
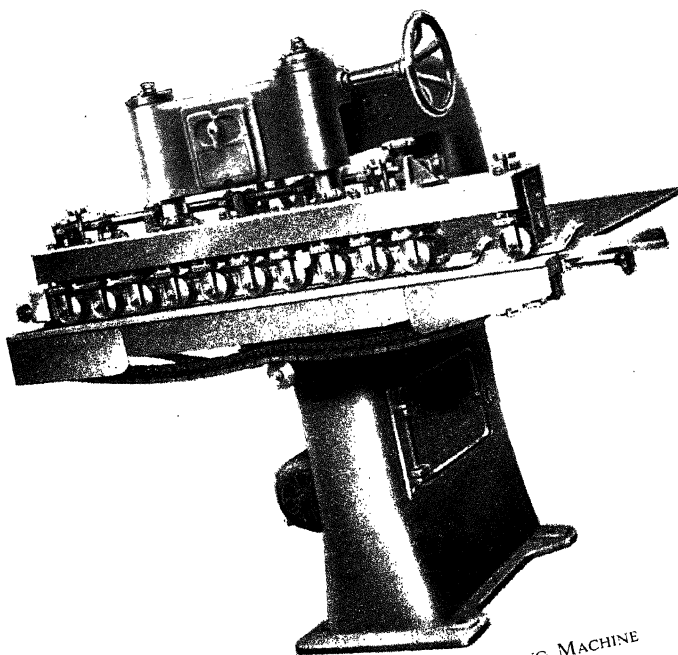
PLATE 4. TAPELESS VENEER JOINING MACHINE
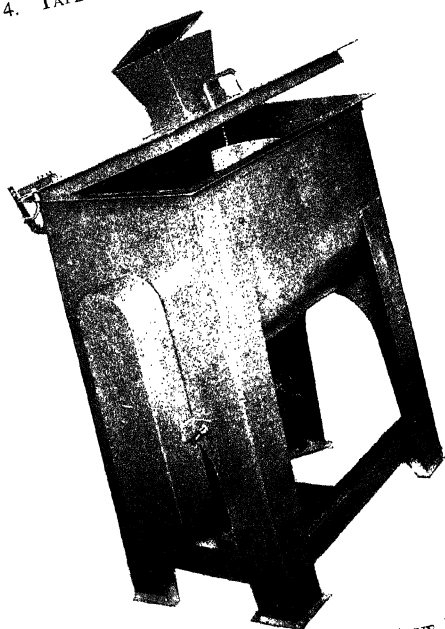
PLATE 5. A MODERN COLD GLUE MIXER
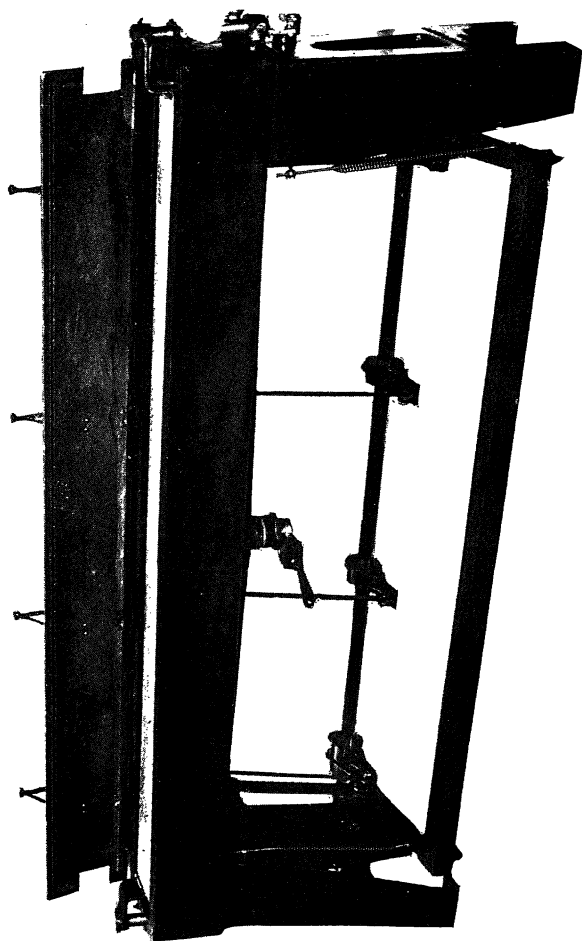
PLATE 6. A TYPICAL EDGE GLUING MACHINE

fitted with electric heating devices, with automatic temperature regulators for melting the adhesive on the veneer edges which are to be joined. Entry of the veneers into the machine and their alignment during travel is automatic and the pressure adjustment is so fine that the thinnest veneers can be passed through without risk of crumpling.

ANIMAL-GLUE PROCESS

Until comparatively recently, animal glue has been used universally for the coating of the veneer edges whilst they are held in the clamp of the veneer trimming machine, the glue being allowed to "gel" before release of the pressure.

The veneers are then separated, the glue allowed to dry and it is subsequently remelted by the heating element of the tapeless jointer combined with the moistening wheel, which simultaneously applies a 10–20 per cent. formalin solution from the heated moistening tank of the machine. This process gives the glue some degree of water resistance and the thermoplastic nature of the animal glue is convenient up to this stage, as the ability to remelt, when desired, renders the trimming and actual joining operations entirely independent of each other.

At the next stage though, the thermoplastic nature of the glue may be a drawback, for in hot-process pressing the glue will remelt a second time and spread out of the joints of the face veneers of the assemblies, causing them to adhere to each other when not separated by cauls.

SYNTHETIC RESIN PROCESSES

To overcome this, synthetic-resin adhesives of the urea-formaldehyde type have been introduced and are now largely used for this operation. Once again, sound arguments can be advanced in favour of each of the two schools—"separate application" or "mixed application". Whichever process is adopted, the coating of the veneer edges which takes place under pressure in the trimmer, as with the animal glue, should be carried out as thinly and evenly as possible and all excess cement wiped off. Failure to do this will result in clogging of and difficulty in cleaning the joining machine. A stiff bristle stencil brush is a suitable tool for the coating, which must be on both edges of the veneers which are to be joined. Immediately the operation is completed the veneers should be removed from the clamp and separated.

The Ready-mixed Application

This requires the use of hardeners, which are mixed with the urea-formaldehyde resin in the proportions stated by the manufacturer. The mixing takes place before the veneer edges are coated. There is usually a choice of at least two hardeners, slow ones being used for temperatures of 300° F. (149° C.) and up and fast ones for temperatures of 200–300° F. (93–149° C.). The advantage of the slow hardener is the longer pot life at room temperature, which allows more time between the coating of veneers under pressure in the trimming machine and the bringing together of the veneers in the edge-to-edge. This, owing to the thermosetting nature of the adhesive, must take place while the mixture is still tacky.

This permissible time of assembly varies according to the room temperature (see Chapter 10), the thickness, type and moisture content of the veneer and the hardener, but it is never more than a normal working day and may be much less. The main disadvantage is that the required joining temperature, 300–500° F. (149–260° C.), is apt to cause edge buckling and uneven shrinkage of thin veneers. The fast hardener, with its lower temperature requirements, obviates this latter difficulty but substitutes for it the disability of still shorter working life, which under certain conditions may be as little as one hour.

In general, the high temperatures, by reliance on more heat and weaker hardener, favour high speeds of joining. Messrs. Bakelite give as typical: 80 ft. of jointing per minute at 500° F. (260° C.), against 40 ft. of jointing per minute at 300° F. (149° C.). Their cement G10911 possesses the useful feature of being coloured bright red, so that dry spots on the veneer edges can be detected readily.

Equipment

The vessels used for mixing and holding the adhesive should be of glass, tin, iron or earthenware, not copper, brass or bronze.

Cleaning of vessels should be performed with cold water. The life of the brushes will be lengthened if several are used alternately, so that each can be put to soak before the adhesive commences setting in the base of the bristles.

The separate application method

A separate application method has been developed by Messrs. Aero Research, Ltd., and their Aerolite 304F involves

much of the same technique as the animal glue and formalin application, plus the advantages of creating-heat and highly water-resistant joints.

As with the animal glue and the mixed resin applications, the cement is applied to the veneer edges while under pressure in the trimmer, but the hardener, which in this case is applied separately, replaces the formalin solution in the edge-to-edge joiner and is applied by the moistening wheel of the machine. As the cement is in a stage of arrested development until it meets the hardener and the two do not contact until the veneers are actually joined, a time lag of several days can be allowed to elapse if necessary between the coating of the edges and the final jointing of the veneers. It is never advisable to leave the veneers unjoined too long after trimming because the edges will not remain straight indefinitely.

This method requires a temperature of 300–350° F. (149–177° C.), which is below the range at which most of the trouble with edge buckling and shrinkage of veneers occurs. The makers impress on users the importance of thoroughly stirring Aerolite 304F, which contains insoluble fillers which tend to separate out in containers which have been standing undisturbed for any length of time. A note of caution is also sounded regarding the hardener, which is strongly acid and which, if allowed to splash on the flesh, is likely to cause dermatitis (see Chapter 16).

CONCLUSIONS

The separate application method, apart from allowing an almost unlimited time lag between the coating and the joining, saves any possibility of waste of material, through too quick hardening, and also obviates the labour involved in mixing small quantities of cement and hardener.

The ready-mixed application, when carried out at high temperatures and with a slow hardener, gives the higher jointing speeds, but has certain disadvantages which have been described. The fast hardener, which overcomes these disadvantages, suffers from short working life.

The animal glue and formalin process is cheaper than any of the resins and has no effect on the skin. It remains perfectly satisfactory with cold-process veneering, but does not give as fast joining as do the synthetic resin cements.

Chapter 13

LIQUID AND OTHER READY-
PREPARED ADHESIVES

MANY people regard liquid adhesives simply as ready-prepared glues for use by amateurs engaged on household repairs. Certainly those varieties sold in tubes and small bottles mainly serve that purpose and some of them are too expensive to use on a commercial scale.

This does not apply to all varieties, and it is now possible to obtain in liquid, jelly or mixed powder form, either ready for use or only requiring the addition of water, adhesives of many different varieties, some of them basically the same as those described in other chapters of this book, others radically different.

Some are too weak to be of any use in woodwork, while others compare very favourably with powder and cake adhesives.

Owing to the great basic variety of these adhesives, no standard strength tests are available and recourse must be had to the testing of joints.

The U.S. Forest Products Research Laboratory has found that the liquid adhesives tested by them have varied from one which only exerted a binding force of 50 lbs. per sq. in. to one with an adhesive strength of sixty times as much, or 3,000 lbs. per sq. in. They go on to say:

"Liquid glues may be tested by gluing together pairs of specially selected hard maple blocks, placing them in a testing machine and measuring the force required to shear them apart. About 300 specimens representing 26 different glues have been tested in this way at the laboratory. According to the data thus obtained, a high grade liquid glue should have an average shearing strength of not less than 1,700 or 1,800 lbs. per square inch.

"In addition to uniform adhesive strength, it is evident that certain other characteristics are desirable in a liquid glue. When spread upon wood surfaces, it should 'set' and dry rapidly. In its container, it should remain fluid and workable at all ordinary temperatures. It should be elastic and shock-resistant. It should

134

not be unusually susceptible to the action of high temperatures, high humidity, molds and bacteria.

" The study gave evidence that the strength of liquid glue, like that of 'hot' glue, depends largely upon its 'body', or thickness, or, strictly speaking, upon its viscosity. Of 11 liquid glues examined, the thickest or most viscous glues showed the greatest adhesive strength."

The following information gives some idea of the large variety of liquid adhesives which are available for general and specialised woodworking purposes.

1. Fish glues

These are manufactured from the skins, heads, swim-bladders, backbones, fins and tails of fish. The process of manufacture is in some respects akin to that of animal glue. The disagreeable odour which was formerly a characteristic of fish glues can now be largely overcome, as can also the tendency of this type of adhesive to absorb moisture unduly. Both improvements are very largely due to the work of Dr. J. C. Kernot, whose investigations have opened up considerable possibilites for increased use of fish glues.

After cooking and other treatment, the extracted gelatine content is concentrated to the required consistency and preservatives and, in some proprietary brands, perfumes are added.

Fish glues set more slowly than animal glues and their working life is much longer. If kept in properly stoppered containers they remain almost indefinitely liquid in ready-mixed solution, and with their adhesive qualities unimpaired. Their moisture resistance is low.

2. Animal Liquid and Jelly Glues

These have the same general basis and properties as the animal-hot glues, but they do not require cooking, mixing or diluting. Some of them are treated with an acid, which keeps them in solution or causes them to flow from a jelly state at a temperature of 80° F. (27° C.) or slightly less. They are labour-saving glues for all general purposes where high moisture and heat resistance are not important.

They should be applied to both the surfaces which are to be joined and the adhesive should be allowed to become tacky before

pressure is applied to the joint. They must remain under pressure for several hours. Surplus glue can be removed easily with a knife when dry.

Rawlplug "Duroglue" is typical of this class of adhesive.

In a slightly higher temperature range, but well below the animal-hot glues comes "Croid". This is a ready-mixed animal glue in jelly form. It is made direct from the glue liquor and is specially treated to give it mould resistance. It is sold in tins which are placed in hot water to put the glue into solution. No cooking is required. Best results are obtained when it is used at 120° F (49° C.). The method of application is as already described.

3. Casein-Latex Solutions

Casein-latex solutions, with varying proportions of the two principal ingredients, are sold for special purposes, usually for sticking wood to other materials. They are described in more detail on page 75 of Chapter 7, "Caseins".

4. Ready-mixed Casein Powder Cements

These are available for mixing with cold or tepid water. It is important that the powder is kept dry. Only the required quantity should be mixed, as any left over will be unusable after a few hours. Most of these cements have fairly high resistance to moisture and excellent heat resistance. No heat is required in their preparation and they can be used in any temperature. For further details of casein cements see Chapter 7.

5. Cellulose Adhesives

These generally have a nitro-cellulose basis and consist of a transparent liquid, sold in tubes, bottles and tins. They must be kept air-tight, otherwise they will rapidly solidify, in which event they can only be brought back to normal by the addition of a suitable solvent such as amyl acetate.

Cellulose adhesives are inflammable, but they must come in contact with a naked flame before they will ignite.

Provided air is kept away from cellulose adhesives and they are stored in a cool place, they will remain in good condition for a fairly lengthy period.

Best results are obtained from cellulose adhesives by applying thin coats to the surfaces to be joined, which should then be brought together and pulled apart again, then after the adhesive

has dried, a second thin coat should be applied, and the pieces should be brought together a second time and held under pressure until dry.

The important feature of cellulose adhesives over ordinary glues is the fact that when dry they are both waterproof and heatproof, whereas ordinary glues are not. This makes these adhesives valuable outside the woodworking industry, for use largely in repairing crockery.

The best known brand is Rawlplug Durofix.

This type of adhesive sets quickly and is transparent. It is more expensive than ordinary glues, but as a little goes a long way, the initial cost is not a serious factor.

6. Synthetic Resin Adhesives

Those usually sold in ready-mixed form consist of urea-formaldehyde resin and hardeners in powder form for mixing in water. Instructions as to proportions of powder and water are always given by the manufacturers. For a general description of these adhesives see the section headed "Cold-pressing varieties of U.F. cements" in Chapter 10, "Synthetic Resin Cements".

7. Bitumen Adhesives

Bitumen adhesives, used for laying wood blocks, cork squares, linoleum, etc., to concrete, are normally either of the cement or plaster type or alternatively of the bituminous type. Bitumen alone, when used as an adhesive, has the disadvantage that it has to be melted on the site and applied hot.

Ordinary liquid preparations on a bitumen base fall into two main classes:

(1) Mixtures of bitumen with suitable solvents to act as thinning agents, and

(2) emulsified bitumens.

Suitable compounds in both classes are on the market and are applied cold, by spray or brush. They can be relied upon to give reasonable satisfaction if due allowance is made for the fact that the medium, whether it be solvent or, in the case of emulsified products, water, has to evaporate from the cement and this largely takes place into the wood or cork slab.

It is usual to make allowance for the swelling of the wood by means of an expansion gap under the skirting, but the same

precaution is often overlooked with cork slabs and curling and unevenness of the floor surface results.

There are on the market, in addition, a few special adhesives which depend for their set on some form of hydraulic action induced in the cementitious material. For instance, if a suitable bitumen, rendered fluid with solvent, has incorporated in it a percentage of ordinary Portland cement, it is obvious that it can be made to set to a solid product by the use of water in the mix. It is also possible to take advantage of other chemical reactions to induce the set and this is done in one or two proprietary materials.

The advantage of these materials, which are so viscous that they are applied by trowel, is that the hardening takes place chemically and there is no evaporation or infiltration of solvent or water into the material which is being stuck down.

3. Marine glues

Materials described under this term are generally not adhesives but are used principally for caulking the seams of decks.

APPARATUS FOR PREPARATION
AND APPLICATION OF ADHESIVES

I N each chapter on an individual adhesive, the apparatus most suitable for its preparation and application has been mentioned and the process of preparation described. This chapter gives a general description of the types of apparatus available for use with the different adhesives.

P R E P A R A T I O N

The first stage in the preparation of an adhesive is the careful weighing and measuring of the constituents. A good pair of scales of a suitable size and not of the spring balance type is a necessity.

Should the weights be avoirdupois and the mixing formula metric or vice versa, the following equivalents may be useful.

1 oz. = 0·028 kg.

1 lb. = 0·454 kg.   1 kg. = 2·205 lbs.

Volume measurements should not be used for dry materials. Pails and containers for mixing should be constructed only of the materials advocated in the chapter on the particular adhesive in question.

All bulk supplies should be kept cool, dry and in the packages in which they are delivered. In most cases it is necessary to re-seal any balance of a package which is partially used. Strict cleanliness is an essential in the preparation department. With some materials precautions must be taken to protect the skins of those who are handling them (see Chapter 16, page 158).

An important point to consider in planning a factory is the advantage or otherwise of having a central kitchen for the preparation of adhesives. The size and general layout of the factory buildings, as well as the processes employed and the types of adhesives which are to be used, all have a bearing on the question.

Centralisation has the following advantages:

(1) That only one "cook" need be employed. In a large factory he is a full-time "cook", and in consequence he can be trained to become a specialist and there is much less likelihood of errors in mixing than where a number of operators in various departments are employed as part-time "cooks".

(2) It relieves a number of foremen of a responsibility.

(3) There will be economy of capital outlay, due to the absence of duplication of mixing equipment.

(4) There will be economy of installation costs, due to elimination of multiple power, water and, in some instances, heating points.

(5) There will be economy in maintenance and running costs of apparatus.

(6) There will be a saving of adhesive, due to the one-man control of storage and the bulk mixing.

(7) Cleanliness is easier to maintain in a central kitchen, which is apart from the production shops, than it is where mixing takes place in a number of productive departments.

(8) There will be no lost production time due to operators having to take time off for mixing and cooking.

(9) With some adhesives, there will be less risk of dermatitis.

Departmental mixing can claim the following advantages:

(1) Mixers and cookers can be mounted so that the adhesive flows direct into the spreaders or troughs.

(2) No hand or truck delivery service of mixed adhesives will be required and less buckets or containers will be needed.

(3) The foreman of a department has the question of continuity of supply under his own control. With the central kitchen this last point need not create any difficulty if proper liaison is maintained between the "cook" and the departmental foremen. If this is not done, there will be waste of material or "hold up" in gluing.

Mixers and Cookers for Animal Glue

For large-scale mixing and cooking, a hot-water-jacketed cooker with a mechanically driven agitator is needed. The heat may be supplied by steam, gas or an electric immersion heater. Whichever source is chosen, there should be an automatic control with a prominently placed thermometer, as animal glue is easily spoiled by excessive heat. The agitator paddles are fitted on a vertical centre shaft, which is motor driven and geared to give 20—25 r.p.m. The paddles must be long enough nearly to touch the side and the lowest one must rotate close to the bottom of the container. The container should be fitted with a lid to prevent skin forming on the glue, and with a sluice type draining valve at the base for drawing off the glue. The outer jacket must also have a draw-off tap for water.

For smaller-scale production, combined glue makers and heaters are built; they too can be thermostatically controlled, and consist of a trough of water, heated by steam, gas or electricity, which contains a plate perforated with one or two large circular apertures, to take the lidded cookers, and a varying number of smaller circular apertures to hold the glue-pots. The stirring of the glue, in such cases, is usually carried out by means of wooden hand paddles.

For still smaller production, the glue is cooked in the double-jacketed pot in which it is used on the bench. Heating in this case too may be by any of the methods already described.

All apparatus used for animal glue should be cleaned with hot water; a steam hose attachment is useful for this purpose.

Mixers and Cookers for Vegetable-Starch Glues

These are also jacketed, but are provided with steam and water connections, so that the adhesive when prepared can be cooled expeditiously. They are fitted with paddles, similar to those in the animal-glue cooker, but they revolve at 30–40 r.p.m.

Cleaning of apparatus is the same as described for animal glues.

Cold Mixers

These are used for casein, vegetable proteins and resin adhesives. A machine for mixing these adhesives is illustrated in Plate 5. Inside the trough is fitted a horizontal shaft, mounting six paddles

in such a way that the ingredients are drawn into the centre from both ends, so that perfect mixing is ensured.

A reduction-geared drip-proof motor, fixed on to a platform at the base of the machine and fitted with a Renold duplex chain, drives the shaft and paddles. The top of the machine has a hinged lid with a splash-proof surround fitted inside. The paddles are automatically stopped by means of a link arrangement from the lid to the switch when the lid is opened to fill the mixer, and so conform to Home Office Regulations.

To prevent the powder hardeners from blowing back, as would happen if they were put in with the main lid open and the paddles in motion, a small funnel with a lid is fitted on top of the main lid to allow hardeners to be introduced and mixed while the paddles are in motion.

The machine is fitted with a suitable sluice-type draining valve. A strong and quickly removed sheet-metal guard is fitted over the Renold driving chain. The capacity of the mixer is 17–20 gallons.

SPREADING EQUIPMENT

The four principal methods of applying glue are by brush, roller spreader, gun, or trough with rise-and-fall action.

Brushes

For small-scale production, a brush in the hands of an experienced worker is the best. Whether the brush should have long or short, stiff or soft bristles or whether fibre should be used has been set out in the chapters describing the individual adhesives.

Spreaders

For large scale *edge-jointing*, either single roller spreaders or perforated plate, edge-gluing machines are used. The roller spreaders should be fitted with covers to prevent the glue being contaminated by dust. The glue reservoirs are generally of the jacketed type, so that heat for animal glue or cold water for prolonging the working life of cold-synthetic adhesives may be circulated. An adjustable scraper bar is provided for regulating the glue flow on the roller. An alternative means of application is the edge gluing-machine, which is really a trough, obtainable in varying lengths and fitted with a perforated horizontal plate. This perforated plate normally lies submerged in the adhesive,

but rises up when the treadle connected to it is depressed. When raised, surplus glue runs back through the holes, leaving sufficient only to glue the edges of boards which are contacted to the surface of the plate. Treadles may be foot or electric operated and the troughs, which are provided with lids, are jacketed the same as the roller spreaders. An edge-gluing machine is illustrated in Plate 6.

Both roller spreaders and edge-gluing machines should be provided with sluice draining valves.

Electrically Driven Double Roller Spreaders

These are invaluable for large-scale primary gluing, such as veneering or the manufacture of plywood. To spread two surfaces, the veneer or board is simply passed between the upper and lower rollers. To spread one side only, two veneers face to face, or two boards or one board and one veneer are passed through.

These machines are supplied with rise-and-fall feed rollers and numerous variations to meet the requirements of different types of adhesives and to allow for heavy or light spreads. They also have doctor bars or rolls for controlling the glue feed to the spreading rollers. Machines for hot applied adhesives are arranged for steam or electric heating. For adhesives ranging between 60 and 100 lbs. of liquid glue per 1,000 ft. of single glue-line, such as animal, casein and vegetable, which require heavy spreads, steel rollers are used which usually have longitudinal grooves varying from 6–12 to the inch. Occasionally spirally grooved rollers are used; groovings are by no means standardised yet and different manufacturers make considerable variations in the outline, pitch and depth of these corrugations and these differences affect the "weight" of the spread as well as the suitability of the roller for adhesives of varying viscosity. It is advisable to arrange a "try out" before purchasing a machine; or to have an agreement that the rollers will be exchanged if found unsuitable for a particular adhesive. Spreaders for synthetic resin adhesives have rubber-covered rollers grooved longitudinally or spirally and with the corrugations ranging between 16 and 24 to the inch, suitable for the lighter spreads of 25–60 lbs. of liquid usually employed with synthetic resins. Wear of the grooves of the rollers must be watched carefully, as worn rollers give an uneven and extravagant spread, which is fatal to good gluing with any adhesive.

It is advisable to check the glue spread periodically, and this

143

s the simplest way of doing it. Weigh 1 sq. ft. or 10 sq. ft. of veneer before passing it through the spreader. Weigh again after passing through. The difference will be the weight of glue for the spread on *two* sides of the veneer. Multiply the difference by 500 in the case of 1 sq. ft. and by 50 in the case of 10 sq. ft. and you have the weight in lbs. per 1,000 ft. of *single* glue-line.

Some spreaders, chiefly those for hot-press synthetic resins, are now fitted with a recirculating pump for emptying the mixer into the reservoir under the lower spreading roller and for supplying an easily controlled amount of adhesive to each roller. It is of no use with mixtures having very short working life. Another use for the recirculating pump is in cleaning the spreader, when it can be used for flushing.

Mechanical spreaders must be cleaned at frequent intervals, and unfortunately, for it is dangerous, much of the cleaning must be carried out with the rollers in motion. Brushes, not cloths, should be used for this operation, and machines should be fitted with an easily accessible, quick stopping and reversing safety device.

Glue Guns

Glue guns of the compressed-air spray type are an advantageous method of application in certain processes where a thin mixture is used. Guns and spray lines must be cleaned frequently, as once the adhesive has hardened in them, they are ruined.

In addition to spray-guns, plunger actuated cylinder guns, somewhat similar to grease guns, are sometimes employed, particularly for bedding panels into framing on building sites. Casein is usually the adhesive chosen.

APPARATUS REQUIRED AND METHODS OF APPLYING PRESSURE AND HEAT TO FLAT OR CURVED WORK

W HILST the amount of pressure required will vary according to both the species of timber and the variety of adhesive, it remains a fact that adequate pressure is essential during the setting of all adhesives if their full joint strength is to be developed. Moreover, for that joint strength to be reliable, the pressure must be maintained *during the whole of the setting process.* For this reason "rigid" pressure, such as that exercised by the screw type of clamp, is never wholly satisfactory in primary gluing. This sounds a paradox until it is appreciated that natural wood at all times and adhesives during the bonding stages are both comparatively easily yielding substances. In primary gluing, where there are a large number of glue-lines and veneers to the inch, it follows, therefore, that the only effective form of pressure is one that can automatically compensate for and *follow up* the "yield" of the materials which are under pressure. Emphasis must be placed on the fact that these remarks about "follow through" apply to *primary gluing only,* where the adhesive alone forms the joint. In secondary gluing—that is, in building up components—the joint is usually already made by a machine which forms a dovetail, a corner lock, a mortise-and-tenon or a dowel-and-socket and the adhesive is employed to turn the "key" on the "lock" at a certain fixed place. In such cases, a screw pressure, which is employed to bring the joints together and squeeze out the surplus glue, may be all that is needed, and in fact a "follow-through" pressure is not always desirable.

Types of Presses (cold)

Where production is on a scale sufficiently large to justify their installation, the most effective power-operated presses are those

10   145

of the hydraulic or piston actuated types, both of which do steadily follow up the "yield" of the materials which are under pressure.

For many types of small-scale production, quite effective presses can be improvised which will maintain continuous pressure by employing dead weight loading or indirect weight loading. The former is simply the modern version of the sensible practice of the ancient Egyptian, who used stone slabs and sandbags as weights and the latter is the application of the weigh arm principle which allows adjustment by increasing or decreasing the number of weights suspended from the arm, as well as by moving the weights along the arm.

Where screw-type presses or clamps must be used for primary gluing assemblies, it is advisable to turn the screws again one or more times after the assemblies have had the first pressure applied.

A screw-clamping device which is used in "cold" presses to increase their output is the H-beam and retaining rod or turnbuckle screw-rod device. A number of the H-beams are placed in line across the assembly, both above and below it, with the ends of the beams projecting beyond the edges of the assembly. When hydraulic pressure has been applied, the top and bottom H-beams are connected up together by means of the screw rods which have clips on their ends which engage the flanges of the H-beams and which are tightened up by means of a tommy-bar inserted in the turnbuckle in the middle of each tie rod. When all the tie rods have been fully tightened, the press is opened, the assembly removed in its retaining clamps, and the press is ready for service again.

Screw Clamps

It is not possible within the scope of this work to describe all the screw clamps which are available, but for edge-jointing and· general assembly they are made for bench use in simple forms, such as metal "C" clamps, sash clamps, or wooden hand clamps with two screws, as well as in the form of steel trestle clamps and the more elaborate edge-jointing types for building up in stacks or for use in rotary clamping machines, which are rotated by hand, foot treadle or electric motor.

For mass-production assembly work, several machine manufacturers specialise in supplying mobile roller mounted single purpose screw clamps for the easy squaring, assembly and
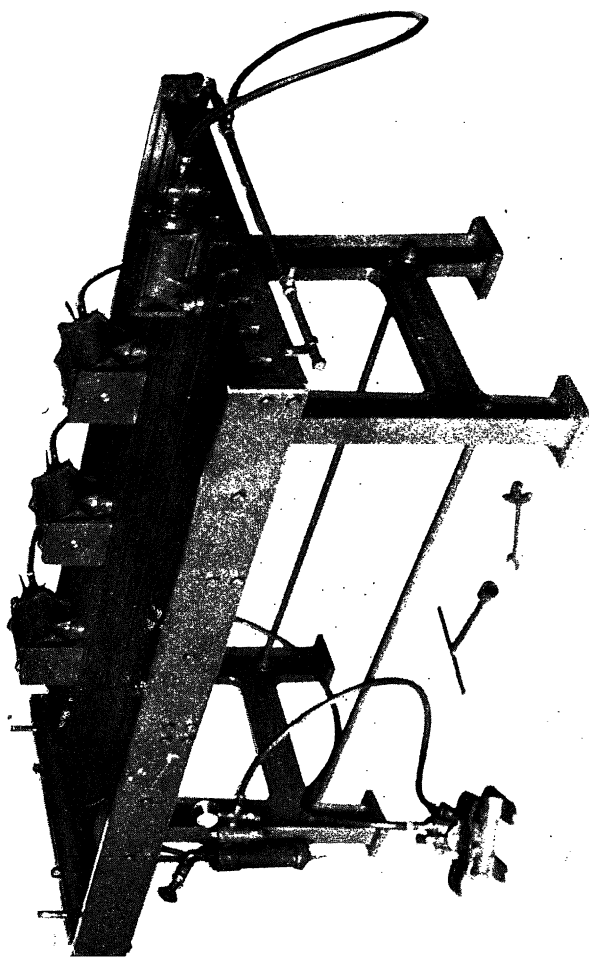
PLATE 7.   A UNIVERSAL PNEUMATIC CLAMP TABLE

107

gluing up of such articles as boxes, drawers, cabinets, bed-ends, bow ends, chairs and settees. Some of these clamps revolve so that additional work can be carried out to all parts of the frame while it remains under pressure.

Pneumatic Clamps

Pneumatic clamping machines, which carry out all the mass-production assembly operations outlined above and give a "follow through", if required, are among the engineer's most efficient and labour-saving contributions to speedy glued assembly during the past few years. In addition to single-purpose machines, general-purpose machines are also made which have the tables so designed that the clamping cylinders may be varied in number, slid along the side of the table as desired and fitted to one or more of its sides. To suit various sizes of work, the tables of these versatile machines are fitted with adjustable stops which slide in the inverted "T" slots machined in the steel table. Bolt-on table extensions can also be provided. These machines provide instantaneous application of pre-determined pressure at any points desired along both sides and both ends of the table. All the cylinders are under instant control individually, by means of a separate valve fitted to each and collectively by means of a foot valve. A pneumatic clamp table of the type described is illustrated in Plate 7.

HISTORY OF HEAT IN PRESSING

Heat in the pressing process is applied for different reasons to different adhesives:

(1) With thermoplastic adhesives it is applied to keep them liquid until pressure is applied or to remelt them after application and "gelling" so that they stick when pressure is applied.

(2) With some cold-setting adhesives, it is applied to speed up the setting process.

(3) With thermosetting adhesives, it is the heat which causes the set, by polymerisation and condensation in synthetic resins, or by coagulation with some of the blood-albumin formulæ.

With most of the older adhesives, heat was not necessary to ensure the set, but in primary gluing particularly—i.e. the making

147

of plywood and in veneering—it is applied frequently to speed up production.

For the hot-pressing synthetic resins, and some blood-albumin formulæ, carefully controlled heat is an essential at the time of pressing.

Open-type Presses with Cauls

. For animal, casein and vegetable adhesives, the open-type cold presses, either hand or hydraulically operated, were used universally until a few years ago for all large-scale production.

When animal glue is used on large surfaces, it "gels" before a large number of boards or veneers can be prepared and put into the press. To remelt it so that it will stick when the pressure is applied, it is customary to use cauls with the open-type presses. These cauls usually consist of thin sheets of aluminium or zinc, slightly larger than the assemblies. These are heated in a gas oven or on a jacketed and steam-heated plate and then placed between each assembly in the press before the pressure is applied. Under careful supervision much excellent veneering has been produced throughout the ages by this method, but it is a crude process, more suited to the small workshop than the large factory, and is not to be compared with the modern precision processes which are detailed later. Quite apart from the amount of labour and manhandling involved, it is difficult to control and equalise the original temperature of the cauls and still more so to know their temperature at the time when the pressure is finally applied after the delay which occurs in the loading. Moreover, the assemblies at the bottom of the press will have had heat applied for a considerably longer time than those at the top, and this is likely to result in starved joints and penetration of the glue through some of the veneers. For small cabinet production, particularly for fancy veneering and repair work, the same principle has been applied for centuries, a hot iron being used as the caul to reheat the glue and lay the veneers. Ordinary electric irons or specially constructed electric veneer hammers are the favourite tools now employed. Whilst casein cements and vegetable-protein adhesives set without heat, their set is speeded by heat, and hot cauls, as already described, are sometimes used to speed their production in cold presses. Another method employed with caseins is to have the cold presses situated in rooms which are kept up to a temperature of 70–90° F. (21–32° C.), but to carry out the actual gluing in a cool room.

Hot-and-cold and Hot, Multiple Daylight Presses

The demand for highly water-resistant plywood for aircraft construction in the 1914–18 war caused the development of the blood-albumin adhesives. They in their turn created the first need for greater and more scientifically controlled heat than was possible with cauls, and the synthetic resins intensified the demand. Out of these needs were evolved the hot-and-cold as well as the hot, multiple daylight presses. The first type is used chiefly for animal glues and the second for synthetic resins.

Basically they are the same, inasmuch as both are equipped with a whole series of daylights, separated by steam-heated aluminium platens: but whereas in the hot-type presses for thermo-setting adhesives, the platens are hot all the time, in the hot-and-cold types for thermoplastics, there is a cold-water circulating system which, by means of pumps, drives the steam back into a cylinder on top of the press and passes cold water through the platens to cool the boards and "gel" the glue sufficiently to complete the bond. The hot presses are usually of a much heavier type than the hot-and-cold and they are designed to develop considerably higher temperatures as well as greater pressure, to meet the demands of heat and pressure called for by the synthetic resins.

Both these types of presses have four or more heavy rigid columns which support a massive structural head, below which are ranged the steam-heated platens. When the press is open, the steam-heated platens have equal openings, known as "daylights", between them, into which are inserted the assemblies for pressing. The presses open and close hydraulically by means of two or more rams.

The relatively light types of press usually employed in the hot-and-cold process close with a downward movement but most of the heavy types employed in the hot process close in an upward direction, the lower table rising up towards the head.

Heat and Pressure for Curved Work

Until a few years before the war there was only one way of making curved plywood and veneering curved sections or mouldings. That was by rigid pressure applied usually in one direction, more rarely in two, and exerted against a form or mould the reverse of the finished article. This method entailed extremely accurate purpose-made jigs for each individual section, made no

allowance for variations in size or section due to shrinkage and imposed limitation on the choice of adhesives due to the difficulties of applying regulated heat to the joint at the time when the pressure was applied.

Just prior to the war an enormous advance was made by the introduction of omnidirectional fluid pressure, which not only maintains steady pressure in spite of any variations in sections but also obviates the need for all purpose-made moulds for veneering of solid sections and cuts out one of the two moulds or matrices formerly required when building up curved plywood sections. The media usually employed to achieve this fluid pressure are compressed air, steam, hot water or a combination of two of them used in conjunction with rubber sheeting.

There are two principal methods of using this rubber-sheet technique:

(1) is the external mattress pressure method,

(2) is the rubber enclosed-mould or vacuum process.

External Mattress Pressure Method

In this method the veneers are first cut to size, jointed and, if coated with synthetic resin adhesive, are allowed to dry in the normal manner. The veneers are then placed in position over the moulding which it is desired to veneer and fixed temporarily there by tacks, staples, tape or the new high-frequency method described at the end of this chapter. If curved-section plywood is to be manufactured, then the veneers to form the plywood are placed into position and secured temporarily over the solid "former" to which they are to be shaped and pressure and heat are applied by inflating a rubber mattress or bag with hot water or steam against the outside of the assembly; in other words, the mattress becomes the outer mould.

In one type of machine used in this process, the mattresses lie in the bottom of metal troughs and the mouldings or "formers" covered with their veneers are pressed down on to the mattresses by means of pressure devices over the trough. It can be supplied with hot and cold connections if desired for use with animal glues or other thermoplastic adhesives, or with hot connections only, for use with thermosetting adhesives.

The same principle is also employed in an autoclave (pressure tank) type of machine with a flat table and curved section steel cover. Where this is used, the "former" or moulding is placed
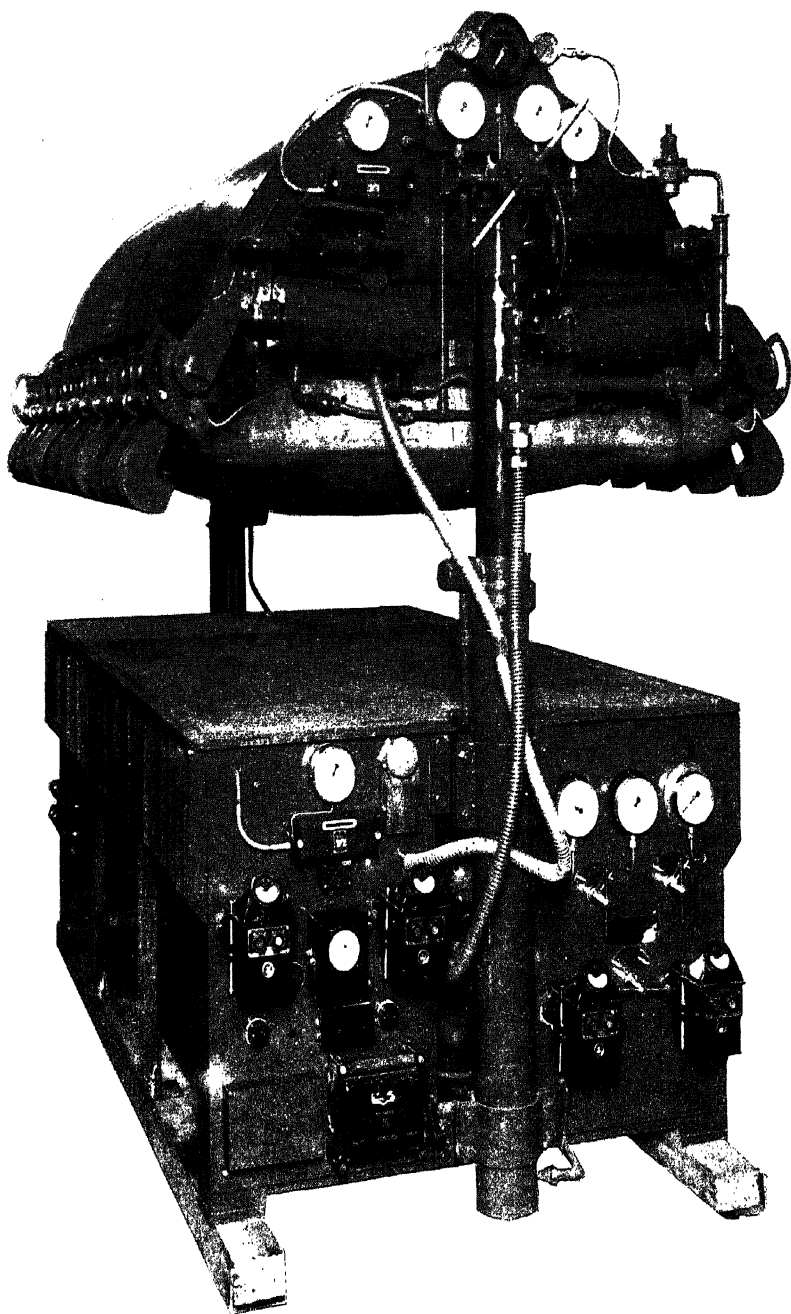
PLATE 8. A MODERN COMPRESSED AIR PANEL SHAPING AND VENEERING PRESS
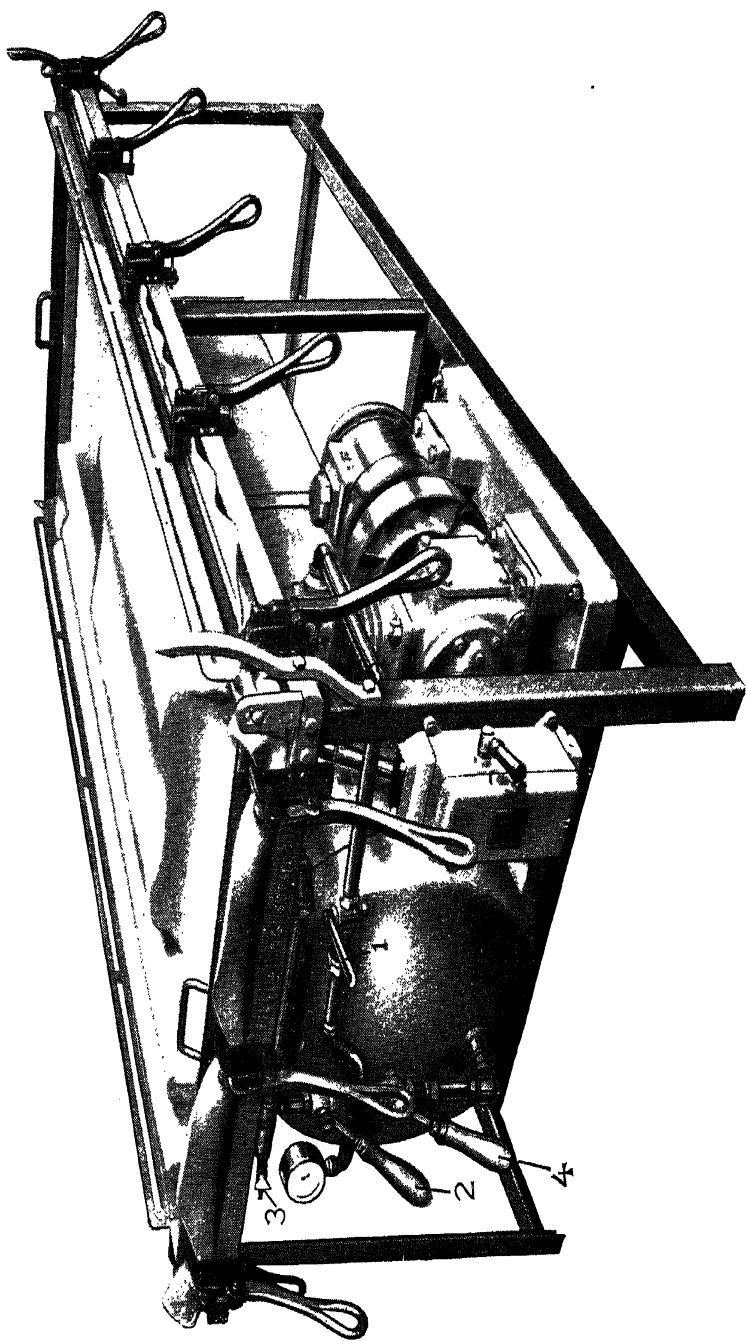
PLATE 9.   A VACUUM VENEER PRESS

on its back on the table, with the veneer fixed temporarily over it. The deflated mattress is placed on top, the curved section cover closed down tightly and the mattress then inflated with steam or hot water until it fills in the whole of the space between the cover and the moulding. When concave assemblies are being built up or when veneering is being carried out to concave sections, the mattress is inflated inside the moulding. The latest variation of this principle is the compressed-air panel shaping and veneering press, which uses a rubber sheet instead of a mattress. Plate 8 shows this machine open.

This machine is a complete unit and only requires one electric connection to be ready for use. When the top head has been raised to its full height the "former" is placed on the bottom table, which is heated and thermostatically controlled. The veneers, which have been previously coated with a suitable synthetic resin adhesive, are placed on the "former". The top head is then allowed to come down, which, being hollow, has a rubber sheet stretched across the face of it and fixed to the outside. It is then clamped in a solid position, thereby hermetically sealing the interior of the press where the "former" is placed.

Underneath the table of the machine there is placed an air-compressor direct coupled to a motor and also a large compressed-air storage tank.

The next operation is to allow the compressed air to go into the domed top head to press the rubber sheet and the glued veneers to conform to the shape of the "former". The work is allowed to remain for the necessary time and the expiration of this time is signified by the ringing of a bell according to the time given for the job, which depends on the thickness—namely, 15–20 minutes for panel making or 6–8 minutes for veneering.

This machine may be used for a long series of narrow panels such as drawer fronts, or larger panels, or it can be used for veneering mouldings in multiple.

One of the special features of this machine is that, with the compressed air, it will exert a total pressure of approximately 70 tons.

The Rubber Enclosed-mould or Vacuum Process

In this process the moulding or assembly, prepared as already described, is enclosed inside the rubber bag. The assembly, in its bag, is placed in the autoclave, which is then sealed. The

rubber bag has an exhaust outlet, to allow the air from the bag to be sucked out, which goes through the domed top of the autoclave. The autoclave has an inlet valve so that steam and air can be pumped in to provide the necessary heat and pressure against the deflated rubber bag enclosing the assembly. In a variation of this process, the moulding or assembly is covered by a rubber sheet which is clamped to the floor of the autoclave, so as to make an airtight connection with it. The air is then withdrawn through outlets in the floor of the machine and external pressure is applied as described above.

Autoclaves for this process are made either in the form of tables with hinged covers, somewhat similar in appearance to Plate 8, or they may be complete cylinders with a door at one or both ends, through which the assembly is wheeled on a transfer car, operating on a track.

The rubber bag or sheet processes already described all rely for their pressure either wholly or partially on externally applied fluid pressure, but there is another type of press, the vacuum press, which applies the whole of the pressure by sucking the air away from inside the rubber sheet and drawing it tightly to the shape of the assembly or "former".

It is an inexpensive and quite satisfactory method for certain shapes, provided that cold adhesives or those requiring little, and not rigidly controlled, heat can be used. It is mostly employed in the cabinet-making trade.

The machine which is illustrated in Plate 9 consists of a heavy oxygen-welded stand, a steel table, under which a large cylinder, a vacuum pump and direct-coupled electric motor are built in; and of an adjustable steel frame, which fits over the rubber sheet. The rubber sheet is hermetically closed in by means of eccentric levers.

Above the iron frame is fixed a wooden table provided with a number of round holes. On the bottom side of this wooden table the holes are connected by grooves, which by means of two pipes connect to the large cylinder approximately 7 ft. 3 in. × 2 ft. diameter. By means of the vacuum pump the air is drawn out of the cylinder, with the result that vacuum is created which presses the rubber sheet on to the goods to be veneered at a pressure of up to 15 lbs. per sq. in.

The operation of the press is as follows. When pressing shaped doors, etc., the "former" is placed on to the table. On

top of the "former" are then placed the objects to be pressed or veneered. According to size, a number of panels can be pressed in the one operation by placing the panels side by side. If warm glue is used, it is recommended to put a warmed-up sheet of lino or zinc or aluminium caul on top of the work piece. The rubber sheet is then drawn over the frame on top of this and, by means of eccentric levers, the rubber sheet is hermetically sealed up. Now the valves connecting the closed-in area with the cylinder in which vacuum has been created by the compressor are opened and the air is quickly drawn out. The rubber sheet presses itself round any shape according to the "former". The cylinder and also the pump are of such large dimensions that an electric motor of $3\frac{1}{2}$ h.p. is necessary. The vacuum created corresponds, as mentioned above, to a pressure of approximately 15 lbs. per sq. in. After the glue is set, air is again let under the rubber sheet and the press can be unloaded and the next operation can start.

When veneering mouldings, these are placed at narrow intervals side by side until the whole area is filled up and the pressing operation is the same as above.

Moulds

When shapes are being built up by the rubber-sheet technique, a mould has to be used for one face. This mould, or "former", may be made out of many materials, such as solid or laminated wood, shaped plywood, sheet or cast metal, concrete, or a combination of some of these materials.

In deciding which is the most suitable, consideration must be given to:

(1) First cost.
(2) Number of "cookings" required.
(3) Type of adhesive and whether heat transmission is required.
(4) Hardness of surface.
(5) Strength required.

The first cost of wood is likely to be the least and it is easy to alter, but its life will probably be the shortest and it is bulky and difficult for heat transmission. Braced plywood construction is usually a little more expensive, but is tough, light and does not absorb as much of the heat. Both solid wood and plywood moulds

require a hard surface finish to protect them against bruising and to obviate the squeeze-out of the adhesive at the joints. Some users cover the joints with thin cellophane to catch the surplus glue.

Well-stiffened metal moulds cost more, are difficult to alter and are only justified for a long production run, but they have a much longer life and cut down the time of the bonding cycle owing to their good heat transmission.

Rubber Sheeting

Both natural and synthetic rubber are used; the former sometimes with and sometimes without a fabric base, the latter always with fabric. The process calls more for flexibility than elasticity and fabric does add strength. It is desirable, though, to keep the sheeting as thin as strength requirements permit, in order to facilitate heat transmission and obviate the difficulties caused by folds and overlaps. The life of the sheeting will vary according to whether it is being used as a sheet or in bag form, the type of curves which are being pressed and the medium employed to exert pressure. Rubber will deteriorate less under conditions of steam alone than when subjected to a mixture of steam and air, which tends to oxidise it. As usual, though, each advantage has its counterbalancing disadvantage, for steam application alone may raise the temperature to the figure at which set of the adhesive takes place before adequate pressure can be applied. Sheets last longer than bags; the latter will require attention or may even have to be discarded after anything from 50 to 100 cookings. They should always be adequately reinforced at vents and valves. Attention is being given to the possibility of producing an inexpensive single-usage specially treated paper bag.

The Adhesive

For all the rubber-sheet processes, except that illustrated in Plate 9, a synthetic resin adhesive is almost an essential in order to meet the following requirements:

(1) Long assembly periods, to allow for the complicated wrappings necessary for some of the required shapes. During this period the adhesive must not be tacky.

(2) The flow period in the autoclave must be a fairly long one, to allow the various layers to slip into the required position before the curing or set takes place.

154

(3) The temperature in the autoclave must not be too high, otherwise the bag will suffer.

(4) At the right moment rapid curing of the adhesive is necessary in order to obtain the maximum number of pressings per day.

As most steam-heated autoclaves do not function effectively at temperatures of less than 230° F. (110° C.) and bearing in mind the other requirements listed, the adhesive which has been found most suitable so far is a phenolic or fortified resin, which can be pre-dried after spreading, will flow again and remain plastic at temperatures between 180° F. (82° C.) and 200° F. (93° C.) and finally harden at a temperature around 230° F. (110° C.).

Pressure and the Veneer

In general, pressure requirements for simple curved work need not exceed 50–75 lbs. per sq. in. but for acute or complicated curves 100 lbs. or even more may be demanded, owing to the resistance of the veneers to the curvature. Where a choice of veneers exists, some consideration is therefore advisable in the selection of the most flexible one that will suit the purpose for which it is intended. The use of part alcohol as a solvent for a phenolic resin will assist in making the veneer flexible.

HIGH-FREQUENCY ELECTRIC HEATING

Until the introduction of high-frequency electric heating, the only practical application of electricity for curing or setting adhesives was by means of resistance coils or plates. Although these were perfectly satisfactory for work on a laboratory scale, their heavy consumption of current made them unpractical for commercial production. The introduction of synthetic resins, requiring in some cases heat above boiling point to set them, made the finding of a form of heat that could be applied direct to the glue-line an urgent necessity, unless the use of these types of adhesives was to be seriously limited.

With heating other than electric, the heat has to pass through the wood to reach the glue-line, and in consequence the thicker the assembly, the longer is the time taken and the greater is the heat loss in reaching through to the glue-line. In fact, gluing with hot-setting adhesives beyond a certain thickness of wood (say

about 1 in.) ceases to be practical because the outer surface of the wood, which is in contact with the caul or platen, becomes damaged through overheating. With high-frequency, or radio-frequency heating, as it is sometimes called, any number of glue-lines can be heated direct by electrodes transmitting the heat *through* the whole high-frequency field of the assembly, which is placed between them in the press. In other words, the heat is generated internally in the assembly. *The horizontal glue-lines*, being electrolytes, are thus made hotter than the surrounding wood and with this method of heat application the wood will be at a temperature around 240° F. (116° C.) when the glue-line is at 300° F. (149° C.). The thickness of the assembly imposes no restriction whatever on the heating of the glue-line or danger of damage by heat to the wood, which in the hot process is of necessity made hotter than the adhesive.

It will be readily seen that the possibilities opened up by this new method are immense, as the speed of temperature increase is regulated by power used and not by thickness of wood; moreover, the temperature at a "near" glue-line is the same as at a "far" one.

In some cases the electrodes are placed top and bottom of the assemblies and parallel to the glue-lines and these flat electrodes are then insulated from the press, Alternatively, the press may be used as one of the electrodes.

An alternative method, which is favoured by some manufacturers, is to place the electrodes vertically against the sides of the assemblies, it being claimed that when the electrical energy travels along instead of at right-angles to the glue-line there is less resistance.

It looks as though high frequency will eventually supersede all other heating methods for curing or setting synthetic-resin adhesives.

Portable high-frequency generators are now being supplied which are specially designed for this work.

In addition to the ordinary high-frequency heating processes, there are various special patent processes in which the conductivity of the glue-line is increased. In the "Tego-Wiro" process, the Tego glue film is supplied spread on to a fine wire gauze instead of the normal paper core and the electric current is passed through the glue-line while the assembly is under pressure.

In the "Gallay" patent process the increased conductivity is

obtained by introducing 20 parts or more by weight of acetylene black into the adhesive.

Spot Gluing

The "Pye" high-frequency gun, which has been produced recently, applies spot-welding methods to glue setting. It is an invaluable portable tool with an entirely different field of application from that of the larger sets. One of its important uses is in tacking veneers at intervals to hold them in position over shaped mouldings or curved "formers" which are being prepared for making curved plywood or veneering solid mouldings by the rubber-bag processes. The use of this handy tool eliminates tacks. tape, etc.

Chapter 16

DERMATITIS

REQUENT reference has been made in preceding chapters to dermatitis. Dermatitis is an inflammation of the skin, usually starting with irritation and redness. Blisters may appear and when these break septic infection is liable to occur. Dermatitis is, however, not contagious.

Occupational dermatitis is caused by contact of the skin with certain materials used in the process which is being carried out. The hands and arms are therefore generally first affected. All persons, however, are not equally susceptible, and whereas one operator may contract the disease when handling one reagent, another may be quite immune to the same material. As will be explained later, the adoption of certain precautions can, in the majority of cases, prevent dermatitis, and the fact that it is an unknown quantity whether or not a given operator will be affected by a material which is known to promote the complaint makes the universal adoption of precautions a vital necessity. It must not be assumed, moreover, that because an operator has handled a given material for months or even years without trouble, that he is completely immune; it is possible that some change in his general health may make him suddenly susceptible.

In working with adhesives, strong alkalis or strong acids are amongst the materials which are most likely to cause dermatitis. In the case of synthetic resins, the constituents chiefly causing the trouble are the formaldehyde and the hardener, and in casein cements the caustic soda causes the trouble.

Intensive study of the complaint has established that the correct method of fighting industrial dermatitis is to adopt preventive measures, and the preventive routine which should be insisted upon is the protection of the skin while at work, together with the observance of scrupulous cleanliness.

Protection of the skin can be effected by the use of rubber gloves or the application of a "barrier" substance.

The use of gloves is open to objection because they are easily damaged and perishable. If they have rotted and become porous

or if they are not kept clean, they actually harbour the attacking substance and thus do more harm than good. Moreover, a careless worker may forget to put on his gloves before starting work, suddenly remember them and put them on after his skin has already been smeared with the irritant, and the ensuing trouble is then likely to become more acute than if there had been no sheath. If, however, gloves are provided, the wearer before putting them on should make quite sure that his hands are clean and that the gloves are free from holes and clean and dry inside. It is also desirable to dust the interior with powder before wearing.

The better preventive course to adopt is the use of a "barrier" cream. A good barrier substance must be non-irritating to the skin and, moreover, must not destroy the natural fats in the skin and cause it to become dry and brittle; it must be non-soluble in the substance against which protection is required; easy application is essential, and the resultant film must be reasonably adherent and not crack or peel off; it must be non-slippery and non-sticky, so as not to interfere with work; finally, it must be easy to remove after work by simple washing, without the aid of a special cleaner.

There are several proprietary brands of barrier creams on the market which meet these requirements, and effective barrier substances dry rapidly, become invisible and usually afford protection for several hours after application, even if high temperatures are experienced. The manufacturers produce a range of creams and they should be consulted to determine which cream in the series provides specific protection against a given irritant. Sulphite soap, as recommended in Form 366 issued by H.M. Stationery Office, should also be made available to workers.

If workers are not supplied with barrier creams, they invariably try to expedite the removal of adhesives from their persons by using strong soda solutions or solvents. These in themselves are causes of dermatitis.

Even the use of barrier creams is insufficient without observing scrupulous cleanliness. Before work commences, when work is finished and at meal intervals it is essential to wash and dry the hands and arms carefully, paying particular attention to the skin between the fingers, the cuticles and any wrinkles. In shops where dermatitis is likely, epidemics can definitely be stemmed and even prevented by insistance on regular and vigorous washing. As an example, can be quoted the experience of a management during

the war in a factory using a synthetic resin which was known to be a severe irritant. Cases of dermatitis were becoming increasingly frequent, with resultant heavy losses in man-hours. Lecturing the employees on the need for cleanliness was not sufficient. The management therefore took drastic steps; all stoppers were removed from wash basins, each employee was provided with a clean towel daily and every worker was compulsorily made to wash under running water before starting work, at each meal break, and before leaving the factory on ceasing work. Under these conditions, even working with this highly irritating resin, dermatitis was completely stamped out in a few weeks.

It cannot be emphasised too strongly that in cases where dermatitis is suspected the individual should seek immediate medical advice, as in the early stages the complaint yields to treatment, but becomes increasingly more difficult to cure when medical treatment is delayed. Recurrence then becomes more probable as well.

Of dermatitis it can indeed be said that prevention is better than cure.

SUMMARY CHART OF PROPERTIES AND CHARACTERISTICS OF DIFFERENT CLASSES OF WOOD-WORKING ADHESIVES

11

Property or Characteristic	Animal Glue	Liquid Glue	Vegetable Starch
Dry strength based on joint tests.	Low to very high.	Very low to high.	Medium to very high.
Moisture resistance.	Low in general; fails rapidly; resistance can be improved by addition of chemicals.	Deteriorates rapidly with some varieties; the nitrocelluloses have very high resistance.	Low; fails rapidly.
Rate of setting.	Rapid.	Medium to rapid.	Slow to rapid.
Working life.	Up to a day.	Several hours to many days.	Several weeks.
Consistency of mixed glue.	Varies from very thin to very thick according to changes of temperature.	Variable from thin to thick.	Thick.
Temperature requirements.	Important for the glue, the wood and the room.	Heat required to use some glues.	Unimportant; used at ordinary room temperature.
Mixing and application.	Soaked in water and melted; applied warm by hand or mechanical spreaders; easiest glue to use by hand.	Requires no mixing; usually applied cold or warm by hand.	Mixed with water and alkali; applied cold by mechanical spreader.
Tendency to foam in mixing.	Slight if not mixed too rapidly.	None.	Very slight in most mixes.
Tendency to stain wood.	None.	None with most varieties.	Slight to pronounced with certain woods.
Dulling effect on tools.	Slight.	Slight with most varieties.	Moderate.
Spreading capacity (expressed in sq. ft. of flat surface per lb. of dry adhesive). Extremes reported.	. 20 to 55.		35 to 100.
Common range.	25 to 35.	Unknown.	40 to 60.
Effect on skin.	None.	Irritant with varieties other than animal and fish.	Irritant with some mixes only.

Casein Cements and Vegetable Proteins	Blood Albumins	Synthetic Resins
Medium to very high.	Low to high.	Very high.
Medium; loses some strength when wet, but regains it when dry; deteriorates eventually; rate varies with glue.	High; loses small amount of strength when wet, but regains it when dry; deteriorates very slowly, but usually completely in time.	Very high; some retain nearly 100 per cent. of dry strength when wet and do not deteriorate appreciably even after repeated wettings.
Rapid	Very rapid with heat.	Very rapid with heat.
Few hours to a day.	Several hours to a day.	Few to several hours for liquid forms; several months for films.
Medium to thick; little change with temperature.	Thin to thick; little change with temperature.	Medium for liquid forms.
Unimportant; used at ordinary room temperatures.	Heat is required to set most glues; cold-press formula is an exception.	Heat required for most varieties.
Mixed cold with water; applied cold by hand, mechanical spreaders, can or spray-gun.	Usually mixed cold with water; may be applied cold by hand or mechanical spreaders.	Often applied as received, but sometimes after addition of "catalyst"; the liquid forms are best applied by rubber-covered rolls; a few varities are applied by spray-gun; with film sheet varieties only heat and pressure required.
Slight if not mixed too rapidly.	Slight to pronounced.	Slight.
Pronounced with certain woods.	None, except dark glue may show through thin veneers.	None, although glue may penetrate through thin or porous veneers.
Moderate to pronounced.	Very slight.	Moderate.
35 to 80. 40 to 60.	30 to 100. 40 to 80.	30 to 100. 35 to 50.
Irritant.	No effect with most mixes.	Irritant.

GLOSSARY OF TECHNICAL TERMS
USED IN THIS BOOK

Thanks are tendered to the British Standards Institution for permission to abstract items marked * from B.S. No. 565–1938; to Messrs. A. D. Wood and T. G. Linn, the authors, and Messrs. W. & A. K. Johnston, Ltd., the publishers, for permission to abstract the items marked † from their book *Plywoods*; and to Mr. E. B. Uvarov, B. Sc., A.R.C.S., D.I.C., and Messrs. Penguin Books, Ltd., for permission to abstract items marked ‡ from *A Dictionary of Science*.

Taken generally, some of the terms defined hereunder may have a broader meaning, but the definitions given cover the terms as used in this book.

ADHESION. The tendency of two surfaces to remain attached when in contact: the wetting of a surface by a liquid is due to the adhesion of molecules of the liquid to the surface.

ADHESIVE. Compound used to joint two pieces of material together.

AGEING OF PLYWOOD. A term used to designate the period between the completion of the bonding process and the stage at which the joint has developed maximum strength. Alternatively, a term used to express time in use or under test conditions of exposure.

†AIR-DRY. A term used when the moisture content of timber is in approximate equilibrium with surrounding atmospheric conditions.

‡ALBUMINS (Albumens). Group of water-soluble proteins occurring in many animal tissues and fluids—e.g. egg-white. Cf. also Blood-albumin.

ANIMAL GLUE. A gelatinous body made from the bones or hides of animals.

ARBONEELD. A specialised process for impregnation for timber in the board by treating wood with a solution of methylolurea.

ASSEMBLIES. Boards or plies the surfaces of which are coated with glue and covered with veneer ready for pressing.

ASSEMBLY TIME. The period that may elapse between the coating of the wood with adhesive and the application of pressure.

AUTOCLAVE. A cylindrical tank to withstand the necessary moulding pressures of the flexible bag process.

BLISTER. A spot or area where the veneer does not adhere to the core.

*BLOCKBOARD. A board having a core of blocks, each not exceeding 1 in. in width, cemented or glued face to face to form a slab which is cemented or glued between two or more outer plies with the direction of the grain of the core blocks running at right angles to that of the adjacent outer veneer.

BLOOD (Blood albumin). Blood adhesives, sometimes known as soluble dried blood; in some formulæ set by chemical reagents and in others by heat. Highly water resistant.

BOND. The adhesion of the adhesive to the two wood surfaces at their junction.

GLOSSARY

BUTT JOINT. Cf. joint.

CASEIN. Cheesy substance precipitated from milk when curdled.

‡CATALYST. Substance which alters the velocity of a chemical reaction but is itself unchanged at the end of the reaction.

In gluing it is used for accelerating the set or hardening and is sometimes referred to as a hardener.

*CAUL. Flat sheets of metal, plywood or fibreboard used to support and separate the glued assemblies in the glue pressing operation.

CELLULOSE ADHESIVE. Adhesive on a nitro-cellulose base.

CEMENT. An adhesive substance, usually a powder mixed with a liquid, and set by irreversible chemical reaction. With some cements, heat and pressure are needed to produce the chemical reaction.

†CLAMPS. The device, usually consisting of I-beams and turnbuckle rods, which holds the package of plywood (or glued strips of wood) under pressure supplied by the press, used in the glue pressing operation.

†CLIPPER. The shearing machine or guillotine used to cut veneers to width.

‡COHESION. Holding together; force holding a solid or liquid together owing to attraction between the molecules. Decreases with rise in temperature.

COLD PRESSING. The term is a misnomer, as it is usually applied to synthetic resin adhesives which do not require hot presses but which do normally require summer temperatures in order to set.

‡COLLAGEN. Organic substance belonging to the albuminoids; chief basis of cartilage and connective tissues of animals. On boiling with water gives rise to gelatin.

‡COLLOID. Substance in, or capable of being brought into, the colloid state; substance which, in solution, does not pass through parchment paper.

‡COLLOIDAL SOLUTIONS. Solutions of colloids; substances in the colloidal state; e.g., solutions of starch, albumin, colloidal metals, etc. Such solutions differ from ordinary solutions of "crystalloids" in the following respects: the particles of the dissolved substance are far larger, and hence will not pass through parchment paper, which may be used to separate a substance in the colloidal state. The particles are electrically charged, and generally all possess the same electric charge of the same sign. Two types of colloidal solution are recognised: lyophilic ("solvent-loving") and lyophobic ("solvent-hating"); the two classes being also sometimes termed reversible or emulsoid sols, and irreversible or suspensoid sols. Lyophilic sols are easy to prepare by direct contact with the solvent and are difficult to precipitate; the solution is far more viscous than the solvent. Lyophobic sols are difficult to prepare, easy to precipitate, and the viscosity is much the same as that of the solvent.

Lyophilic sols may set into a jelly or gel; lyophobic sols do not form gels. The dissolved substance is termed the disperse phase, the solvent the dispersion medium.

COMPENSATOR. Appropriate particulate fillers and fluids, other than water, incorporated in cold-setting, gap-filling glues for the control of the chemical setting reactions (W. G. Campbell).

COMPREGNATED WOOD (Compreg). A combination of the terms "compressed" and "impregnated".

CONDITIONING PERIOD. Cf. Ageing.

COOKER. A jacketed container for preparing adhesives which require heat in their mixing.

‡CRESOL (hydroxytoluene). $CH_3C_6H_4OH$. Liquid resembling carbolic acid in properties.

DAYLIGHTS. The openings between the platens of a press into which the assemblies are placed for pressing. There is one less daylight than platen in every press.

DERMATITIS. Inflammation of the skin.

DOCTOR ROLL OR BAR. A device for limiting the amount of liquid glue on a roller spreader.

†DRIER. The kiln or chamber, through which veneers or timber are passed to remove excess moisture.

EDGE JOINT. Cf. Joint.

EQUILIBRIUM MOISTURE CONTENT. The moisture content at which wood does not gain or lose moisture when surrounded by air at a specified temperature and relative humidity.

EXTENDER. Extender or filler used as an addition, particularly with synthetic resin adhesives, in order to reduce veneer penetration or costs, or provide body for gap-filling.

FILLER. Cf. Extender.

FILM. A thin sheet of tissue paper coated on both sides with a phenol-formaldehyde resin adhesive, such as Tego, for placing between layers of wood and bonding by means of heat.

FISH GLUES. Glues manufactured fron the skins, heads, swim-bladders, backbones, fins and tails of fish.

‡FORMALDEHYDE. HCHO. Gas with an irritating smell, very soluble in water. 40 per cent. solution is known as formalin. Used in industry in the manufacture of Bakelite and other artificial resins.

GEL. Gelatinise or become semi-solid.

GLUE. An adhesive substance which sets mechanically by loss of heat, sometimes assisted by pressure or absorption into the wood.

HARDENER. Hardener for resin adhesive—cf. Catalyst.

HIGH-DENSITY PLYWOOD. Cf. Compreg, Impreg.

HIGH-FREQUENCY FIELD. A method of heat generation in a field between the electrodes of high-frequency electrostatic currents. When used in thick assemblies, it is possible to heat the entire assembly in a much shorter time than when external heat from hot plates is applied. Also termed radio-frequency.

HUMIDITY (RELATIVE). The relative amount of moisture in the air compared with dry air and measured by means of wet-and-dry-bulb thermometers.

‡HYDROLYSIS. Chemical decomposition of a compound by water, the water itself being also decomposed, e.g. salts of weak acids, weak bases, or both, are partly decomposed by water; the inversion of cane sugar is a hydrolysis brought about by the action of an enzyme or by boiling with dilute acids.

"HYDULIGNUM." A specialised form of compreg, in which the veneers are bonded with a thermoplastic resin so that top pressure as well as side pressure is applied to the pack to ensure approximately equal shear values in the longitudinal transverse and longitudinal normal to the grain. The impregnation is slight.

‡HYGROSCOPIC. Having a tendency to absorb moisture.

IMPREG. A trade name for impregnated wood that has not been subjected to exceptional compression.

IZOD VALUE. The quantity of energy required to fracture, by a single blow, a specified test piece under specified conditions of test.

"JICWOOD." A specialised form of compreg.

166

GLOSSARY

JOINT. The junction between the edges, ends or surfaces of two adjacent pieces of wood.

Butt joint. A square joint at right angles to the direction of the grain.

Edge joint. A joint parallel to the grain of the wood.

Lap joint. A fault due to the ends or edges of veneers overlapping.

Open joint. A general fault due to the two surfaces not meeting sufficiently closely.

Scarf joint. A bevel joint for extending the length of timber or plywood. The length of a scarf joint is usually fifteen times the thickness, and when properly made is as strong as the plywood.

Starved joint. An indication of deficiency of adhesive through insufficient spread, too rapid absorption or too much pressure.

Sunken joint. A term used to describe a depression along the line of the joint, caused by levelling off of the surface adhesive before it has finished contracting.

*KILN. A chamber for drying timber, in which the temperature and humidity of the circulating air can be suitably controlled and varied.

LAP JOINT. Cf. Joint.

LATEX. Cf. Rubber latex.

LIFE. Cf. Working life.

MELAMINE. A complex ring structure of carbon, nitrogen and hydrogen . atoms; made from calcium cyanamide. Somewhat resembles urea in its chemical behaviour.

*MOISTURE CONTENT. The amount of moisture in timber, expressed as a percentage of its oven-dry weight.

‡MOLECULE. Smallest portion of a substance capable of existing independently and retaining the properties of the original substance.

‡PHENOL. Carbolic acid. C_6H_5OH; white, crystalline solid, m.pt. 41·5° C., with a peculiar "carbolic" smell. Soluble in water, corrosive and poisonous. Used as a disinfectant, in the manufacture of drugs, and in the preparation of bakelite and other artificial resins.

PLASTIC. A material which, at some time in its history, is capable of flow and which on the application of the necessary pressure and/or heat can be made to take up a desired shape.

PLATENS. The plates of a veneer press, often hollow and fitted with a grillage of water pipes, for heating and cooling, between which the glue assemblies are placed for pressing.

†PLYWOOD. A product in which several plies or pieces of veneer are glued to each other or to a lumber core. The grain of any one ply is usually at right angles to the adjacent layer or layers. The use of the term is broadening, and "plywood" may be considered to include products referred to as blockboards, laminboards, stripboards. Boards formed of more than three layers of veneer are usually designated "multi-ply".

‡POLYMERISATION. Chemical union of two or more molecules of the same compound to form single molecules; a polymer of a substance possesses the same empirical formula as the original substance, but its molecular weight is several times that of the original substance.

†PRESS. The machine in which uniform pressure is applied to the panels after glue is spread, to bring the sheets of veneer into intimate contact.

PRIMARY GLUING. Cf. Secondary gluing.

‡PROTEINS. Class of organic compounds of very high molecular weights (30,000–40,000) which compose a large part of all living matter. Protein molecules invariably contain the elements carbon, hydrogen, oxygen and nitrogen; often also sulphur and sometimes phosphorus. Hydrolysis of

167

proteins yields a mixture of various amino-acids. Proteins are essential in food; their function is to be built into the body-tissues. The usefulness of a protein in food depends upon the nature of the amino-acids from which the particular protein is built up, since some amino-acids necessary to the human body cannot be made within the body. Typical proteins are albumin in egg-white; casein in cheese; foods containing a high percentage of proteins include cheese, lean meat, fish and eggs.

RADIO-FREQUENCY FIELD. Cf. High-frequency field.

RESIN (Synthetic). Cf. Synthetic resin.

RUBBER LATEX. The milky liquid in the rubber plant which exudes when the plant is wounded and coagulates on exposure to the air.

SCARF JOINT. Cf. Joint.

SECONDARY GLUING. Process of assembling components by gluing, such as boxes, drawers, doors, furniture, etc., as opposed to "primary gluing" when veneers are glued together to form sheet material such as plywood.

†SHIM. A long, narrow patch glued into the panel.

SOLVENT. The liquid in which the adhesive is dissolved.

SPREAD. The amount of liquid adhesive in lbs. that is applied per 1,000 sq. ft. of single surface.

SPREADABLE LIFE. Cf. Working Life.

SPREADER. A machine fitted with one or more rollers for applying adhesives to wood.

STARVED JOINT. Cf. Joint.

STAYPAK. A specialised heat-stabilised, compressed wood that has been heated during the pressing process to the extent that the lignin flows, resulting in conditions such that the compression is not lost permanently even though the wood may be swollen temporarily by moisture. Although it will swell appreciably under conditions of moisture, it will return to practically the original compressed thickness on drying to the original moisture content.

SUNKEN JOINT. Cf. Joint.

SYNTHETIC RESIN. Term applied to a group of synthetic compounds resembling natural resins.

†TAPE. The strip of gummed paper or cloth used to hold the edges of veneer together previous to gluing.

TEGO. Original phenolic-film glue.

TEGO GLUEFILM-BONDED IMPROVED WOOD. A specialised form of compreg made with Tego Gluefilm and thin veneers.

THERMOPLASTIC ADHESIVE. A term used to describe an adhesive which tends to soften when heated and which when cooled can be softened again by reheating.

THERMOSETTING ADHESIVE. A term used to describe an adhesive which hardens under heat or by means of a catalyst and which cannot be re-softened at any temperature.

‡UREA. Carbamide, $CO(NH_2)_2$; white, crystalline, organic compound, m. pt. 132° C. Occurs in the urine. The first organic compound to be prepared artificially (by Wöhler).

VEGETABLE-STARCH GLUES. Adhesives derived from certain vegetable starches, such as cassava, potato, etc.

*VENEER. Timber in the form of a thin layer of uniform thickness. *Note*— produced by slicing, sawing or rotary-cutting.

‡VISCOSITY. The "internal friction" of fluids, which causes a resistance to change of form. If the fluid is imagined to be subdivided into a series of layers, the forces of viscosity are those forces which retard the more rapidly moving layers.

‡VISCOUS. Having high viscosity; a liquid which drags in a treacle-like manner.

WORKING LIFE OF ADHESIVES. The period during which the mixture remains usable.

BIBLIOGRAPHY

The bibliography which follows, though incomplete, will be sufficient to provide the reader with the titles of works of reference which will afford more intense study of the different branches of the subject.

GENERAL LITERATURE

British Standard Publications.
No. 745—1937. Joiners Glue. (Under Revision).
No. 565—1938. Terms and Definitions Applicable to Hardwoods and Softwoods.
No. 5V3 December 1939. Plywood for Structurally Important Parts of Aircraft.
No. 6V3 July 1943. High-Strength Plywood for Aircraft.
No. 1203 and 1204—1945. Synthetic-Resin Adhesives for Wood. (Under Revision).
No. OOO (in preparation). Casein glue for wood.
No. 647. Methods for testing glues (bone, skin and fish glues).
No. 757. Sampling and testing gelatines.
No. 844. Methods for testing vegetable adhesives.

Commonwealth of Australia, Council for Scientific and Industrial Research.
Gluing Practice, Part I: Animal Glues.
Gluing Practice, Part II: Casein Glues.
Gluing Practice, Part III: Vegetable, Vegetable Protein, Liquid and Blood-Albumen Glues. 1936.

Department of Scientific and Industrial Research (H. M. Stationery Office).
Adhesives Research Committee, Third and Final Report of the Dermatitis Form 367.
Post-War Building Studies No. 3: Plastics.

Forest Research Institute, Dehra Dun, U.P., India.
Indian Forest Leaflet No. 40: Studies on Adhesives, Part IV—Further Note on Prolamin Adhesives. 1943.
Indian Forest Leaflet No. 42: Part I—A study of the Impregnation of Wood with Resins. 1943. By D. Narayanamurti and Kartar Singh.
Indian Forest Leaflet No. 45: Preliminary Studies on Improved Wood. Part II—Laminated Wood. 1943.

Timber Development Association.
Circular No. 6. Wood and Glue. The Mosquito. Chemical Seasoning of Timber.

U.S. Department of Agriculture, Forest Products Laboratory, Madison, Wisconsin.
Age and Strength of Glue Joints. By Don Brouse.
Animal Glues—Their Manufacture, Testing and Preparation. 1937.

BIBLIOGRAPHY

Behaviour of Casein and Blood-Glue Joints under Different Conditions of Exposure. By Don Brouse. 1934.

Blood-Albumin Glues—Their Manufacture, Preparation and Application.

Casein Glues—Their Manufacture, Preparation and Application.

Chemical Treatment of Surfaces for Improving Glue Joints.

Controlled Exposure Tests on Birch Plywood indicate Durability of Water-Resistant Glue Joints. By Don Brouse. 1938.

Copper Salts Improve Casein Glue.

Glues for Use in Aircraft.

Glues for Use with Wood.

Heat-Stabilised Compressed Wood (Staypak). Revised December 1944.

Important Factors in Gluing with Animal Glue.

Increasing the Durability of Plywood. By Don Brouse.

Methods of Increasing Durability of Plywood. 1932.

Method of Testing Hardness of Glue Joints.

Serviceability of Glue Joints. By Don Brouse. 1938.

Strength of Commercial Liquid Glues.

Strong and Weak Glue Joints.

Synthetic-Resin Glues.

Synthetic Resins improve Plywood Qualities. 1939.

The Gluing of Wood. By T. R. Truax.

Vegetable (Starch) Glue. By Don Brouse. 1937.

Water-Resistant Cold-Press Blood-Albumin Glues. Revised 1936.

United States Department of Labor Bureau of Labor Statistics Employment and Occupational Outlook Branch.

Summary of Technological Developments affecting War Production. August 1943.

GENERAL LITERATURE

Astbury, W. T., M.A.: *Fundamentals of Fibre Structure.*

Aero Research Ltd.,: *Technical Notes from the Director of Research and Development.* Aero Research Ltd., Duxford, Cambridge.

Boulton, B. C.: *Use and Manufacture of Plywood and Glue.*

Brown, Nelson C.: *Timber Products and Industries.* Chapman and Hall.

Bruyne, N. A. de: *Why Does Glue Stick?* Wood, March 1940.

Butterworth, B., B.Sc. (of the Building Research Station): *Adhesion and Adhesives, with special reference to Anti-Scatter Treatments for Windows* (reprinted from Chemistry and Industry, 8th and 15th Aug., 1942).

Connell, L. J. C., B.Sc., A. Inst. P. (of G. E. C. Research Labs.): *The Application of Radiant and Inductive Heating to Industrial Purposes.*

Crossley, F. H., F.S.A.: *English Church Craftsmanship.*

Darrow, Floyd L.: *The Story of an Ancient Art.* Perkins Glue Co., Lansdale. Pennsylvania 1930.

Dulac and Rosenbaum: *Industrial Cold Adhesives.*

Fleck, H. Ronald, M.Sc., F.R.I.C.: *Plastics. Whither Plastics?* The English Universities Press Ltd.

Gerry, Eloise and Truax, T. R.: *Effect of Wood Structure on Glue Penetration* (reprinted from the *Furniture Manufacturer and Artisan,* Grand Rapids, Michigan, April 1922).

Hayward, Charles H.: *English Period Furniture.*

Hofton, Dr. J.: *Amino Resins* (Chemistry and Industry, Dec. 1944).

Jourdain, M.: *English Decoration and Furniture* (2 vols.). B. T. Batsford Ltd.

171

Knight, A. G. (of Forest Products Research Laboratories, Princes Risborough): *Waterproof Glues.* Wood, June 1942.

Laucks, I. F.: *Construction Glues.*

Litchfield, F.: *Illustrated History of Furniture.* Truslove & Hanson, 1922.

Morse, F. C.: *Furniture of the Olden Times.* Macmillan, 1902.

Schmitz, Dr. Hermann: *The Encyclopædia of Furniture.* Ernest Benn, 1926.

Shapland, H. P., A.R.I.B.A.: *The Practical Decoration of Furniture* (Vols. I, II, and III). Ernest Benn, 1926/1927.

Symonds, R. W.: *English Furniture,* The Connoisseur, 1929, and *The Present State of Old English Furniture.* Duckworth, 1921.

Tanner, Henry, Jnr.: *English Interior Woodwork of the XVI, XVII and XVIII Centuries.* B. T. Batsford, Ltd., 1902.

Taylor, J. P. (R.C.A. Manufacturing Co., Inc., Camden, New Jersey): *Heating Wood with Radio-Frequency Power.*

Tiemann, H. D., M.E., M.F.: *Wood Technology.* Pitman, U.S.A., 1942.

Tipping, H. Avray: *Grinling Gibbons and the Woodwork of his Age.* Country Life, 1914.

Uvarov, E. B.: *Dictionary of Science.* Penguin, 1942.

Wood, A. D., and Linn, T. G.: *Plywoods.* Johnston, 1942.

Yarsley, V. E., and Couzens, E. G.: *Plastics.*

JOURNALS

British Plastics: various numbers.

Plastics: various numbers.

The Cabinet-Maker: various numbers.

Timber and Plywood: various numbers.

Timber Trades Journal: various numbers.

Wood: various numbers.

TRADE LITERATURE

Against the name of each Company is given a reference to the particular product or products which are of interest in connection with adhesives. No attempt has been made to include every product or even necessarily the principal product of a manufacturer.

Aero Research, Ltd., Duxford, Cambridge: "Aerolite" synthetic resin adhesives.

Alfred Adams, Ltd., West Bromwich: "Alfadite" casein and animal glues.

Bakelite, Ltd., London: "Bakelite" synthetic resin adhesives.

Bardens (Bury), Ltd., London: "Calbar" liquid, jelly, powder and cake skin glues.

Barter Trading Corporation, Ltd., Sole Distributors for: "Beetle" synthetic resin adhesives, manufactured by Beetle Products, Co., Ltd., London.

British Tego Gluefilm, Ltd., London: "Tego" synthetic resin gluefilm.

Casein Company of America: "Casco" casein and "Cascamite" synthetic resin adhesives.

Casein Industries, Ltd., London: "Laitzo" casein adhesive.

Colas Products, Ltd.: Bituminous emulsions.

Commercial Structures, Ltd.: "Staffa" glue heaters and presses.

J. W. Cubbage and Sons: Glue mixers and heaters.

de Vilbiss Paint Spraying Equipment, London: Spray-guns.

Hardan Company, London: Liquid, Scotch, skin and fish Glues.

F. A. Hughes and Co., Ltd., London: "Cellobond" synthetic resin adhesives.

Imperial Chemical Industries, Ltd., London: "Mouldrite" synthetic resin adhesives.

BIBLIOGRAPHY

Innoxa Laboratories, London: "Innoxa" barrier creams.

Interwood, Ltd., London: Presses, cookers, mixers, veneer trimmers, tapeless joining machines, etc.

I. F. Laucks Inc. (U.S.A.): "Lauxite" synthetic resin and "Lauxein" casein and Soyabean adhesives.

Leicester, Lovell and Co., London: "Casco" casein adhesives.

Marconi Instruments, Ltd., London: "Marconi-Ekco" moisture meters.

Neverpart Waterproof Cement Co., London: "Neverpart" casein adhesives.

Pennsylvania Coal Products Co. (U.S.A.): "Penacolite" resorcinol adhesives.

Projectile and Engineering Co., Ltd., London: Glue clamps, pneumatic cramping tables.

Pye Telecommunications: High-frequency guns.

Rediffusion Ltd., London: Radio frequency heating.

Rigidex, Ltd., Wealdstone: "Rigidex" casein adhesives.

H. Schubert, London: "Burkle" brand of presses, cookers, mixers, veneer trimmers, tapeless joining machines, etc.

Society of Chemical Industry, Basle, Switzerland: "Melocol" melamine adhesives.

The General Electric Co. Ltd., London: Radiant and Inductive heating apparatus.

The Improved Liquid Glues Co. Ltd., Welwyn Garden City: "Croid" also cake, jelly and liquid glues.

The Rawlplug Co. Ltd.: Durofix and Duroglue.

The Resinous Products and Chemical Co. (U.S.A.): Synthetic resin and bloodalbumin adhesives.

Union Glue and Gelatine Co.: Animal glues.

INDEX

175

INDEX

INDEX

The first name
in GLUE

In any account of the theory and practice of wood adhesives, the name "CROID" must figure prominently as the pioneer in the field of prepared glues. For more than 35 years Croid has maintained world leadership by research, the development of new techniques, and the highest standards of production.

Its pre-eminence is due in no small measure to the "CROID SERVICE", which exists to study the individual problems of every glue user and to recommend the correct grade of CROID for every job. You may consult the Croid Service confidently on any problem affecting the choice of glue for your own particular needs.

Croid *For Home, Hobby, or Factory*

i
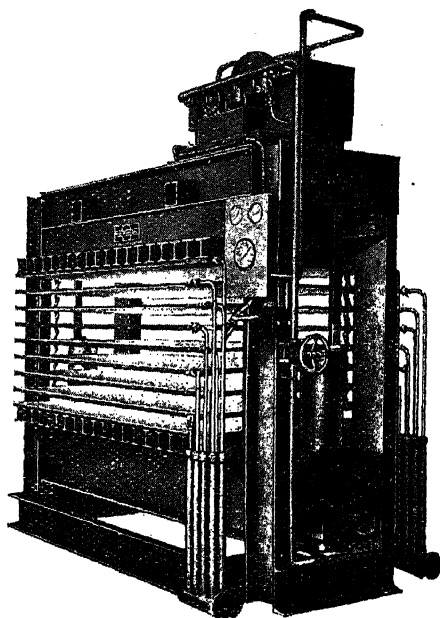
shoes and . . .
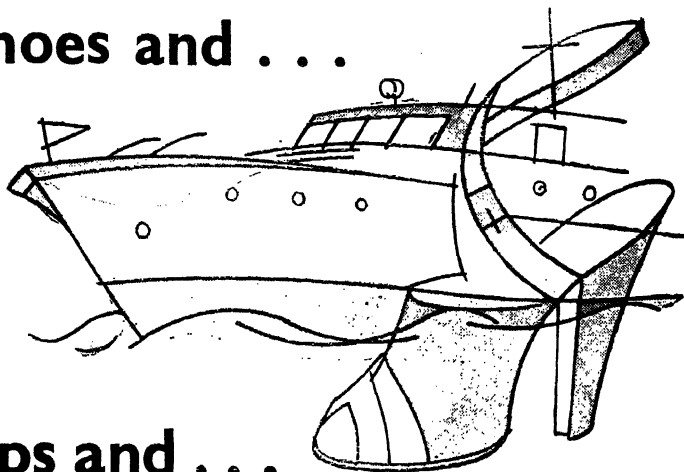
ships and . . .

. . . chairs and houses and tables and doors and windows and tennis-rackets and dinner-wagons and trays, not to mention aeroplanes—Aero Research Limited have produced a range of adhesives and bonding processes scientifically designed to simplify the manufacture of all these and countless other products of wood, paper, metal and plastics.

A unique advisory service is offered by the Company's Duxford laboratories. This consists of :

● A technical staff whose function is to discuss and advise upon the many practical applications of synthetic resin adhesives.

● Publication of a technical service bulletin distributed each month, free of charge, to responsible officials and executives who wish to be informed of the most recent developments in synthetic adhesives and wood technology.

Many subjects of interest to all users of wood have been discussed in these Technical Notes during the five years in which they have appeared. *A postcard to the Technical Service Dept., Aero Research Limited, Duxford, Cambridge, will ensure receipt of a specimen bulletin, and future issues, if required, as they are published.*

AERO RESEARCH LIMITED
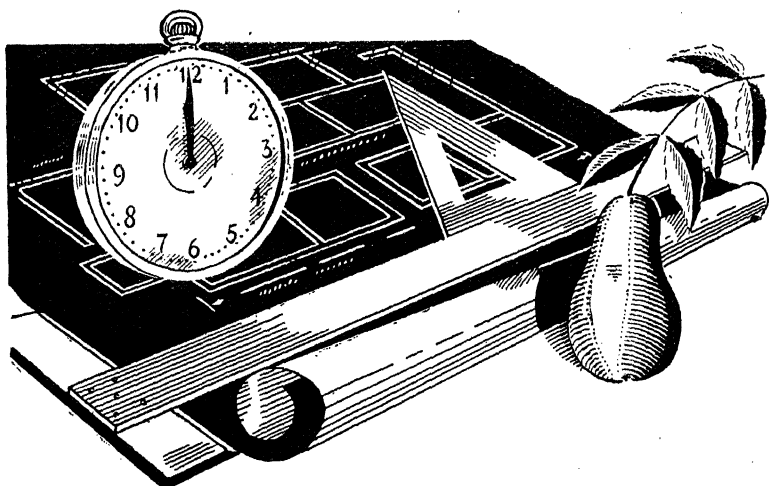
The TIME *is* RIPE

FOR YOU TO CHECK

whether you are using the best available "CASCO" adhesive to suit your wood gluing operations.

FOR YOU TO CONSULT

the Technical Service Department of the "CASCO" organisation on your gluing problems if your production plans are in the initial stages.

There are four recognised groups of Wood Adhesives:

(1) WEATHERPROOF   (3) SEMI-DURABLE, AND

(2) WEATHER-RESISTANT   (4) INTERIOR

The "CASCO" range of over 50 grades covers all four. Send us details of your operations.

CASCO

THE POWER THAT IS BINDING FOREVER